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FACILITY FORM 602

N67 11396
(ACCESSION NUMBER)

(THRU)

139
(PAGES)

1
(CODE)

~~CR-79092~~
(NASA CR OR TMX OR AD NUMBER)
CR-79092

17
(CATEGORY)

GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 4.00

Microfiche (MF) 1.00

ff 653 July 65

Beech Aircraft Corporation

BOULDER, COLORADO

U. S. A.

BEECH AIRCRAFT CORPORATION

Boulder Division

TEST REPORT

No. FR 13632 Date 11/25/64

Rev.	Dates Revised
A	5/5/65

TITLE

FINAL TEST REPORT
FOR
LIQUID HYDROGEN PRESSURIZATION
TESTS

Contract No. NAS8-5331

Customer: National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama

Period Covered: 29 May 1963 - 27 August 1964

APPROVAL SIGNATURES	DATE
Prepared by: Albert R. Lowrie A. R. Lowrie, Test Engineer	6 MAY 65
T. Bielawski T. Bielawski, Group Engineer	6 MAY 65
J. R. Mabbitt, Assistant Manager	

ENVIRONMENTAL TEST LABORATORIES

Boulder, Colorado

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ADMINISTRATIVE DATA

Purpose of Test: To supply pressurization data which will be used to assist in heat exchanger design for the Saturn Missile Program.

Test Specimen: 7000 Gallon 6Al-4V Titanium Test Tank

Manufacturer: Beech Aircraft Corporation, Boulder, Colorado

Number of Tests Conducted: Sixteen (16)

Tests Conducted by: A. R. Lowrie, Test Engineer
Beech Aircraft Corporation
Liquid Hydrogen Test Facility
Boulder, Colorado

Disposition of Test Specimen: The 7000 gallon titanium test tank was destroyed during a test run on 27 August 1964. The Beech Aircraft Corporation is presently awaiting the Government directions as to disposition of the test tank remains.

Abstract: In accordance with Beech Aircraft Corporation Work Order No. 82100, a series of liquid hydrogen pressurization tests was conducted, utilizing the titanium test tank in the thermal test tower vacuum bell. These tests consisted of helium and hydrogen gas for pressurization with four (4) tests including the application of external heat flux.

FINAL TEST REPORT FOR LIQUID HYDROGEN PRESSURIZATION TESTS

1.0 INTRODUCTION - The purpose of the tests described in this document is to satisfy the requirements of Beech TP 13636-3 to conduct liquid hydrogen pressurization tests for the Fluid Mechanics and Thermodynamics Branch of NASA Marshall Space Flight Center, Huntsville, Alabama.

2.0 CHRONOLOGICAL PROGRAM HISTORY

1963 May 29 - Negotiated Contract No. NAS8-5331 with National Aeronautics and Space Administration at the George C. Marshall Space Flight Center, Huntsville, Alabama. The Contract was for conducting a series of liquid hydrogen pressurization tests in the Beech Aircraft Corporation's Boulder Division, Thermal Test Facility. Program completion was set at one year from the Contract date.

June 24 - Substituted the 7000 gallon titanium test tank for the stainless steel test tank, which was shipped to its rightful owner, Edwards AFB, California.

July 19 - Received the first budget authorization for W.O. 82100 NASA Contract NAS8-5331. This included Series "A" testing only.

July 25 - Received supplement #1 to the budget authorization. This supplement to provide for procuring and buildup of the 100 point liquid level indicating system.

July 28 - Submitted drawing of the titanium test tank instrumentation rake.

August 1 - Initiated purchase order for forty (40) Germanium thermometers, calibrated from 20°K to 40°K with an accuracy of ±0.3% above range. The nominal resistance at 40°K will be 10 ±1 ohms and at 20°K will be 35 ±1.5 ohms.

August 26 - Problems were encountered in the contractual requirements for a fast response temperature measurement probe capable of 62.3% of the total temperature change, in two seconds or less, in still air. NASA supplied drawings and test data of a probe used in liquid oxygen, which could meet this requirement.

August 27 - Submitted drawing No. 60358, Liquid Hydrogen Gas Diffuser, to NASA for approval.

September 23 - Received the fast response thermocouple drawings and test data sheet from NASA.

September 25 - Decision is made that Beech personnel will fabricate and test the fast response thermocouples to be used on this program.

October 8 - Designed a prototype fast response thermocouple and submitted both drawing No. 60377 and the model to NASA for approval.

October 31 - Issued Engineering for the following:

a. Liquid Hydrogen Gas Diffuser
b. Propellant System Interconnections
c. Pressurization and Vent Systems Interconnections
d. Instrumentation Interconnections

December 14 - Changed the Germanium Thermometer nominal resistance to 7.5 ±1 ohms at 40°K and 35 ±1.5 ohms at 20°K.

December 26 - Completed the fabrication of a new instrumentation Rake to be used in the Titanium Tank.

December 29 - Installed an Antivortex Baffle in the Titanium Test Tank.

December 30 - Completed the fabrication of 40 fast response thermocouples per NASA specifications. Installed five of these in the NAA Saturn II tank for evaluation purposes, and to determine how well the commutating system would function in conjunction with thermocouples, without amplifiers.

December 31 - Received the fabricated liquid hydrogen gas diffuser and all of the interconnecting spool pieces from manufacturing. Installed the diffuser in the test tank.

1964 January 2 - Started calibration and testing of the fast response thermocouples. The millivolt output was very wide spread in both liquid nitrogen and liquid hydrogen. Data to be presented to NASA in order to determine the procedural variations.

January 19 - Received the first twelve (12) Germanium probes to be used in the test program. The respective calibration curves were included.

January 20-21 - A trip to Huntsville, Alabama was made to establish a clarification of program objectives. Items of discussion included the following itinerary:

a. Program Objectives
b. Testing Sequence
c. Titanium Test Tank and Properties
d. Vortexing Possibilities
e. Instrumentation Locations

f. Pre-Pressurization Procedure
g. Pressurization and the Liquid Hydrogen Gas Diffuser
h. Monthly Progress Reports
i. Recording Sequence
j. A Test Procedure Review
k. Liquid Level System

A meeting was held with the testing personnel on their procedure for the fast response thermocouple calibration. Several factors which might be affecting our thermocouple accuracy were discussed.

January 29 - Revised the heat tower pressurization control system to allow a flow of gas only when the ullage pressure drops below the required operating pressure. This was accomplished by using a pressure switch to control the test tank pressurization control valve.

January 30 - Released the revised test procedure, TP-13632-3, for series "A" testing.

January 30 - Completed the cleaning of the titanium test tank.

January 31 - Conducted a leak check of the titanium test tank.

January 31 - Fabricated the instrumentation cover plate for thirteen (35 Pin) amphenol connectors and for three (37 Pin) copper-constantan connectors.

February 3 - Submitted Progress Report for January.

February 5 - Completed the addition of another arm to the instrumentation rake.

February 11 - Contracted for a data reduction program which will enable Beech personnel to reduce data from MTA-2 magnetic tape through the use of the G-15D computer.

February 15 - Completed the fabrication of the instrumentation cover plate and connecting leads.

February 17 - Completed modifcations to the pressurization and vent system in order to utilize the same flowmeter and provide larger flow rates.

February 19 - The University of Colorado calibrated the vent and pressurization flowmeter to provide flow rates in both directions.

February 25 - Revised the series "A" test schedule due to the NAA Saturn II test program.

February 27 - The five fast response thermocouples in the Saturn II test tank indicated, but time data could not be verified.

February 27 - Received the balance of the Germanium probes which were ordered for the test program.

February 29 - Fabricated a cryostat to be used for the fast response thermocouple tests and calibration.

March 1 - Submitted Progress Report for February.

March 6 - Completed the installation of teflon brackets on the instrumentation rake.

March 9 - Completed the revised instrumentation print for NASA review.

March 11 - Procured a 48 channel copper-constantan automatic thermocouple reference system (ice point) to be used in thermocouple testing and in the test program.

March 11 - M. Nein, NASA Technical Supervisor, visited the Boulder Facility to observe preparations to testing and to discuss the following itinerary:

a. Magnetic Amplifiers and Isolation Transformers to be used with the Fast Response Thermocouples
b. Liquid Level Locations on the Instrumentation Rake
c. Installation of Three Temperature Probes on the Diffuser
d. Revising the Test Schedule
e. Discuss the Possibility of Two Additional Helium Runs
f. Discuss Possibility of Obtaining Helium Samples During Run.

March 13 - Conducted a computer program of height versus volume in the titanium test tank.

March 14 - Submitted curves of titanium properties to NASA.

March 15 - Completed the instrumentation rake wiring.

March 19 - Ordered forty Model 190 Magnetic Amplifiers and isolation transformers. Beech representative to observe equipment and return with two models to Boulder for preliminary testing.

March 31 - Installed a three-way ball valve to enable faster changeover from pre-pressurization to pressurization.

April 1 - Submitted Monthly Progress Report for March.

Released revised Series "A" test schedule.

Drafted fast response thermocouple test procedure.

Contacted the National Bureau of Standards for information regarding the obtaining of helium samples during the test runs. Availability of equipment for analysis was a problem and doubt was expressed as to results which would be obtained.

April 3 - Completed the cryostat test setup for the fast response thermocouple calibration.

April 6 - Contacted by NASA on following subjects:

a. Requested One Run of the Coldest Possible Helium for Pre-Pressurization
b. Photographs of the Diffuser
c. Status of the Two Additional Helium Runs
d. Magnetic Amplifier Status
e. Date for Start of Testing

Started the fast response thermocouple calibration and response test. Modified the cryostat to prevent probes from contacting sidewalls. Installed a limit switch.

April 7 - Thermocouple Calibration and Response Test. The wires broke on the moving parts inside of the cryostat. They had to be run through the movable tubing. The reference probe and the test probes had to be located closer together.

Tested a teflon frame probe (T-7) with a peaked junction. Response very good.

April 8 - Conducted a 40 psia static proof pressure test with gaseous nitrogen on the titanium tank. Results satisfactory.

Thermocouple Testing: Conducted tests on T-8 and T-6 probes. Results were not good. Repeated tests on T-7 with good results.

April 9 - Thermocouple Testing:

a. Fabricated a new liquid level indicator for the cryostat.
b. Modified reference probe in order to immerse it in the test media.
c. Tested some thermocouples to determine effect of peak pointing up, pointing down, and the frame of a variable width.

Received the new 32°F reference oven and installed it in the test setup.

April 10 - Thermocouple Testing: Redesigned the cryostat to correct several problems. Installed two microswitches to supply a trace of the probe travel in and out of the liquid. A support arm was installed to allow smoother operation during probe travel.

Conducted tests on four probes which had not been tested previously.

April 13 - Received the new COX propellant flow meter. Installed the two pressurization valves for the new pressurization system.

Thermocouple Testing: Tested the effect of insulation and varnish on the junction wire of several probes. Fabricated an 18-gauge stranded wire as a frame and tested this. Started testing with the probe junction at various angles to the horizontal. Response extremely poor.

April 14 - Thermocouple Testing: Tested seventeen (17) thermocouples with varying junctions to evaluate the effect upon response.

Contacted the National Bureau of Standards for additional information on the feasibility of helium samples during test runs. Subject included cost of sample analysis and time to accomplish the task.

April 15 - Thermocouple Testing: Fabricated several thermocouples using a solid 20 gauge copper-constantan wire for the frame and 30 gauge for the junction. Response tests were very good so it was decided to test these extensively. Test Procedure involved changing the angle of the junction, shortening the distance between the yoke arms, and varying the angle of the junction with the horizontal during testing.

April 16 - Installed the sixteen (16) skin temperature thermocouples to the outside of the titanium test tank.

Started to install the test tank in the vacuum bell, but were unable to do so due to the wind.

Repaired the thermocouple cable to the vacuum bell for the heat rate computers.

April 17 - Installed the titanium test tank in the heat tower vacuum bell.

Installed the Cox Propellant Flowmeter in the outflow line.

Installed the waugh vent and pressurization flowmeter.

Installed elbows on the titanium tank inlet ports.

Continued thermocouple testing for the effect of the speed of probe travel on removal from liquid to gas.

April 20 - Installed the propellant fill line to the test tank.

Checked out pressurization system valve operations.

Thermocouple Testing: Tested a 1" square frame, a 2", and a 3" model thermocouple. The 3" square model provided the best results. Ran an additional series of tests on this model with very good results. Decided this was the type we would use for the test tank internal temperatures. Started fabrication of forty-five (45) thermocouples of this type.

April 21 - Thermocouple Testing: Continued the testing of our production type thermocouple through various angles at various velocities. Started the official calibration of seven (7) of the forty-five production models. Completed with good results.

April 22 - Completed the fabrication of the forty-five production type thermocouples to be used in the test tank.

April 23 - Prior to final calibration it was decided that the procedure would be to take three (3) millivolt readings and series of ten (10) response tests on each probe.

April 24 - Contacted NASA as to the following information:

a. Pressurization requirements - NASA to send the pre-pressurization and pressurization gas temperatures required for the first series of runs.
b. NASA to conduct the helium solubility tests in their own battleship program.

Inreased the pre-pressurization gas heat exchanger by an additional 100 feet of copper tubing.

Calibrated eleven (11) of the fast response thermocouples (Production Type).

April 27 - Calibrated eight of the fast response thermocouples.

April 28 - Installed new 1" line for helium pre-pressurization.

April 29 - Calibrated six of the fast response thermocouples. Continued work on the helium system.

April 30 - Completed the calibration of the remaining fast response thermocouples in liquid nitrogen.

Installed the vent line to the titanium tank.

Installed helium lines to the control panel.

May 1 - Completed a rerun calibration of the first 14 fast response thermocouples in liquid nitrogen.

Started converting cryostat to liquid hydrogen capability.

May 4 - Encountered problems in liquid hydrogen calibration of fast response thermocouples. Conducted runs at 8 psig, 18 psig, and 38 psig. Data was erroneous.

May 5 - Modified cryostat vent system and installed a pressure switch to control pressure to 11/2 psig. Reading still not satisfactory. Bypassed the copper-constantan connector and readings were good. Ran all leads through the cover and made connections outside of the cryostat.

May 6 - Encountered many leaks when the cryostat was pressurized. Drilled holes for the thermocouple leads and epoxied around each wire.

May 7 - Still encountered leakage around wires. Decided the leakage was coming through the insulation. Stripped the insulation off and epoxied between wire and cryostat cover. Leakage was eliminated.

Completed the magnetic amplifier chassis buildup.

May 8 - Conducted the liquid hydrogen calibration on test thermocouples 1 through 10 at 12, 20, 30, 40 and 50 psia.

May 11 - Calibrated fast response thermocouples 11 through 22 in liquid hydrogen. Stabilized thirty minutes between each change in pressure and one minute between each millivolt reading.

May 12 - Calibrated thermocouples 23 through 33.

Fabricated brackets for installation of instrumentation on titanium tank internal walls.

May 13 - Calibrated Leeds & Northrup potentiometer prior to completing thermocouple calibration.

Completed wiring to the magnetic amplifiers.

May 14 - Installed instrumentation brackets to the internal wall of the test tank.

Installing 30-channel events recorder for liquid level indicating system.

Received authorization to:

a. add two additional helium pressurization tests to the program,
b. modify two of the present series "A" tests, and
c. extend the contract until 30 September 1964.

May 15 - Installed all instrumentation and wiring to the internal wall of the test tank.

Calibrated fast response thermocouples 34 through 45.

Installed the vent and pressurization line to the vacuum bell and to the titanium test tank.

Installed the vacuum bell dome over the test tank.

May 18 - Installed fast response thermocouples to the instrumentation tree.

May 19 - Continued work on the new pre-pressurization system and the instrumentation rake.

May 20 - At the request of NASA, a technical and administrative visit was made to Huntsville, Alabama. Topics of discussion included:

a. Costs of Proof Pressure Testing the Titanium Tank
b. Refund Associated with Platinum Probes
c. Finalize the Four Pending Contract Modifications
d. Costs Incurred to Date Versus Technical Performance
e. Start Date for Testing
f. Additional costs that can be Expected to be Incurred on the Program

Installed pressure regulator in the pre-pressurization system.

Installed thermocouple wires for test tank hookup.

May 21 - Completed installation of Germanium probes on the instrumentation tree.

Terminated ends of the thermocouple multiconductor cable.

Wiring installed to all new valving.

May 22 - Installed Germanium probe and a fast response thermocouple in the test tank outflow line.

Completed the pre-pressurization system to the third level of the tower.

Installed wiring between the patch panel and the magnetic amplifiers.

May 25 - Installed the instrumentation rake in the test tank.

Installed the thermocouple and pressure transducer in the pre-pressurization system.

Continued wiring effort for remote test operation.

May 26 - Installed flowmeter in the pre-pressurization system.

Installed the instrumentation cover plate on the vacuum bell.

Repair damaged thermocouples on the instrumentation tree.

Completed all magnetic amplifier wiring.

May 27 - Completed the hookup of all internal wiring to the instrumentation tree.

Modifying control panel to accommodate new valving.

Completed the circuit for the input to the 30-channel events recorder.

Completed the hookup of all thermocouple leads to the reference oven.

May 28 - Completed allwork in the test tank.

Installed the ullage pressure readout line.

Installed diffuser with 3 fast response thermocouples in the test tank.

May 29 - Prepared instrumentation patch sheet with associated instrumentation locations in the test tank.

Completed the relay panel and installed in the control console.

Completed the installation of the pre-pressurization system.

Completed installation of the pressurization 3-way valve.

Calibrated the three pressure transducers.

June 1 - Submitted Monthly Progress Report.

Ordered helium tube trailer.

Completed all work on the liquid level indicating system.

Commenced with the instrumentation checkouts.

June 2 - Installed the titanium tank manhole cover and started all systems leak checks.

Installed vacuum bell cover.

All systems checkout complete.

June 3 - Started the vacuum pumpdown.

Conducted the liquid nitrogen fill and drain checkout;the following problems were encountered:

a. Pressure switch set to psig rather than psia.
b. Control to the pre-pressurization control valve needed to be reworked.
c. The pre-pressurization regulator did not control properly.
d. The liquid level indicating system required resetting.
e. Changes necessary in the pressurization control system.

June 4 - Corrected all problems encountered in the fill operation.

Conducted another liquid nitrogen fill operation.

June 4 - Discovered a leak in the vacuum jacket cover on the flow control valve.

Located leakage at the vent and pressurization flange on the vacuum bell.

Small leakage was evident on the instrumentation plate.

June 5 - Repaired all leaks.

All systems ready for the liquid hydrogen compatibility test. The liquid hydrogen due Sunday night.

Series "A" test run No. 1 scheduled for Wednesday, June 10.

June 8 - Received the liquid hydrogen as scheduled. Leakage developed on the No. 1 liquid hydrogen storage dewar at the burst disc. While personnel were repairing the leak, lightening struck the heat tower with a fire resulting. Two fluids mechanics were burned and extensive damage to the facility resulted. The liquid nitrogen deluge system was used to control the fire.

June 9-12 - All liquid hydrogen was removed from the facility and an estimation of the damage was made. Plumbing on top of the storage dewars was badly burned as was most of the wiring in the storage wing. Twelve control valves had to be replaced. A large crack in the No. 2 storage dewar vacuum jacket resulted and required welding.

June 15 - July 22 - Rework of the facility to repair damage caused by the fire.

July 22 - Completed checkout of all systems in preparation of receiving liquid hydrogen.

July 23 - Received liquid hydrogen and conducted a liquid hydrogen compatibility test. Encountered several instrumentation problems. These areas were corrected and all systems made ready to start run No. 1 on Tuesday, July 28th.

July 27 - A bad electrical storm over the weekend burned up a transformer and the vacuum pump to the storage dewars. Power transferred to another transformer and the vacuum pump replaced. The liquid hydrogen due next day.

July 29 - The liquid hydrogen did not arrive until the end of the shift. Test scheduled for next day.

July 30 - Started the fill of the test tank for Run No. 1. The propellant flowmeter would not supply a readout. The test tank was drained and the flowmeter removed. A wire was grounded on the vacuum jacket. The flowmeter was reinstalled in the system and checked for a readout. Indications were good.

July 31 - Conducted Series "A" test Run No. 1. Systems looked good.

August 3-9 - Reducing the test data from Run No. 1.

August 10-12 - Prepared test data to be sent to NASA. Started correcting some problems evident in this run.

a. Pressurization and vent gas flow rate set for 750 to 1250 CFM. This problem was corrected.
b. Liquid level indicators not playing properly.
c. Problems with Channels 41 and 63.
d. The three temperatures on Channels 83, 84 and 85 were not reading correctly.

August 13 - Replaced the teflon gaskets at the vent and pressurization gas flowmeter. Used Florablue instead of Teflon material.

Conducted Series"A" Test Run No. 3.

August 14 - Instrumentation working a timing problem.

The cannon connectors on the instrumentation plate were damp and had to be dried out.

Conducted Series "A" Test Runs Numbers 4 and 6.

August 17 - Conducted the following test runs:

Series "A" Test Run No. 2
Series "D" Test Run No. 15
Series "D" Test Run No. 14
Series "A" Test Run No. 5

During run number 15 we could not maintain the 2100 GPM flow rate as required. With the propellant flow control valve wide open the flow rate was only 1650 to 1700 GPM.

August 18 - Conducted the following test runs:

Series "A" Test Run No. 7
Series "A" Test Run No. 6
Series "A" Test Run No. 4

During a preliminary check of the data it was noted that our propellant flow rate was increased by a factor of 2. Investigated problem.

August 19 - Investigation of the problem indicated that we had a 75 millivolt reading at zero flow. Could not locate the cause, but during the trouble shooting of the system, the problem disappeared.

Waited for liquid hydrogen in order to continue testing.

August 20 - Conducted Series "A" Test Run No. 6. The propellant flow rate was still too high. Further investigation revealed a manufacturer's ground was defective in the Foxboro flow controller. Due to the fact that this problem existed in the previous runs, it was decided to rerun all of the previous runs.

Conducted Series "A" Test Run No. 3. Run was good.

August 21 - Conducted the following test runs:

Series "A" Test Run No. 2	Run was good.
Series "A" Test Run No. 4	Run was good.
Series "A" Test Run No. 6	Run was good.
Series "D" Test Run No. 14	Run was good.

August 22 - Conducted the following test runs:

Series "A" Test Run No. 7	No Data on Tape
Series "A" Test Run No. 5	Good Run
Series "A" Test Run No. 7	Pressure Would Not Hold
Series "C" Test Run No. 11	Good Run
Series "C" Test Run No. 12	Good Run
Series "C" Test Run No. 13	Good Run
Series "A" Test Run No. 7	Good Run

August 24 - In preparation to conducting the external heat flux runs, it was determined that the ignitrons in the ignitron power controllers No. 1 and No. 15 were no good. Replaced these with ignitrons from Controller No. 14.

August 25 - Conducted Series "E" Test Run No. 18. Good Run

August 26 - Conducted the following runs:

Series "E" Test Run No. 17	Good Run
Series "E" Test Run No. 16	Good Run
Series "F" Test Run No. 22	Good Run

Problems developed in the heat controller console so it was decided to proceed with the 50 psia proof pressure test of the titanium tank and then conduct the three 50 psia Series "B" tests.

August 27 - The titanium test tank was filled with liquid hydrogen and then the pressure increased to 50 psia. The tank was vented off after a stabilization period and the above operation repeated.

The test tank was then prepared for the first of the three Series "B" Test Runs. During pre-pressurization the operating pressure (50 psia) was reached in 48.7 seconds. After a 7.4 second stabilization the drain operation commenced. At T + 36.8 seconds the test tank ruptured dropping approximately 6000 gallons of liquid hydrogen into the vacuum bell. Extensive damage was caused to the vacuum bell and the heat lamp assemblies. The vacuum bell cover was blown off tearing the support plumbing throughout the tower. The liquid nitrogen deluge system was activated in the tower area and the possibility of a fire was controlled while the liquid hydrogen in the vacuum bell was vaporizing. The cause of rupture is unknown, but the data concluded that there was no over-pressurization.

August 28 - Air Force personnel conducted an investigation of the damage.

August 31 - Started removal of the test tank from the vacuum bell.

September 1 - Removal of the test tank is complete. All work in the heat tower is stopped until further notice.

September 7 - Due to the length of time involved to reduce a test run on the Bendix G-15D Computer at Beech it was decided to transfer the data to an IBM tape for faster reduction.

September 12-13 - Started conversion of the present digital magnetic tape to an IBM Compatible Tape Format.

September 19-20 - Continued Tape Transfer

October 3-4 - Continued Tape Transfer

October 7 - Received all reduced data from NBS.

October 7-12 - Organizing and binding all data runs in separate folders.

October 12 - Delivered all data to Contracts Administration for delivery to NASA.

October 28-30 - In order to clarify some problem areas in the data and to finalize the existing contract, a trip was made to Huntsville, Alabama. The itinerary of this trip included:

a. Test Data Terminology
b. Titanium Tank Information
c. Boiloff Rates
d. Test Report
e. Tour of NASA Battleship Facility
f. Contractural Meeting

November 9 - Started writing Test Report.

3.0 TEST PROCEDURE - Basically all tests in this program were accomplished in the same manner, except for those requiring external heat application. The test tank was filled with liquid hydrogen until liquid level sensor No. 48 indicated a covered condition. A short time was allowed for the level to drop below this sensor and then pre-pressurization would begin. All recorders were turned on five (5) seconds prior to pre-pressurization and allowed to run until the drain operation was completed. Pre-pressurization was controlled by a pressure switch which would automatically close the PPC valve when the operating pressure was attained. At this time the PPC switch was manually actuated in order to hold the valve closed and to switch the automatic control to the main pressurization flow control valve (PFC). The parameter for pre-pressurization was 50 to 80 seconds, which was followed by a stabilization period of 20 seconds maximum.

The drain operation was started by simultaneously opening the fuel flow control valve, FFC, and turning the pressurization valve, PV, to the tank position. Prior to this time the pressurization valve had been turned to the vent position in order to bring pressurant gas up to the required operating temperature. Propellant flow was controlled by a Foxboro flow indicating system which was manually operated to the desired flow rate.

Pressurization during the drain operation was automatically controlled by the ullage space pressure switch. This switch actuated the pressurization flow control valve, PFC, from open to closed positions, depending on the test pressurization requirements. The Appendix "C" Pressurization Control System Schematic will more clearly explain this operation.

At the conclusion of the drain operation, a five (5) minute stabilization period was allowed for the currents to come to rest and for the temperatures to stabilize. The recorders were then run for five (5) seconds and then all systems were secured.

The pre-pressurant and pressurant gases were either helium or hydrogen for all test runs. Some of the tests required the same type gas for both operations, while others consisted of both hydrogen and helium. For all helium applications the supporting facility was a tube trailer attached to the pressurization system. The required helium gas temperatures were either ambient or -300°F. Low temperature control was accomplished by the use of a liquid nitrogen heat exchanger. The ambient temperature gas was taken directly from the tube trailer.

The range of hydrogen gas temperatures, being more widely spread, required the use of a temperature controller and six (6) immersion type heaters. Through the use of this system, the liquid hydrogen was converted into the desired operating gas temperature. As with the helium gas, all ambient temperature gas was taken directly from a tube trailer.

Several runs required the application of external heat flux during the testing operation. This phase of the procedure is being covered in paragraph 5.0

4.0 **TITANIUM TEST TANK INFORMATION** - The titanium tank was built to hold 7000 gallons of liquid hydrogen. It weighs 473 pounds, and has a mass-fraction ratio of 0.897.

The tank was built using annealed sheets of 6Al-4V Eli-grade titanium, supplied by Titanium Metals Corporation of America, to approximately 1/2 standard thickness tolerances. The guaranteed room temperature properties of this sheet are 120,000 psi 0.2% yield strength; 130,000 psi ultimate tensile strength; and 10% elongation.

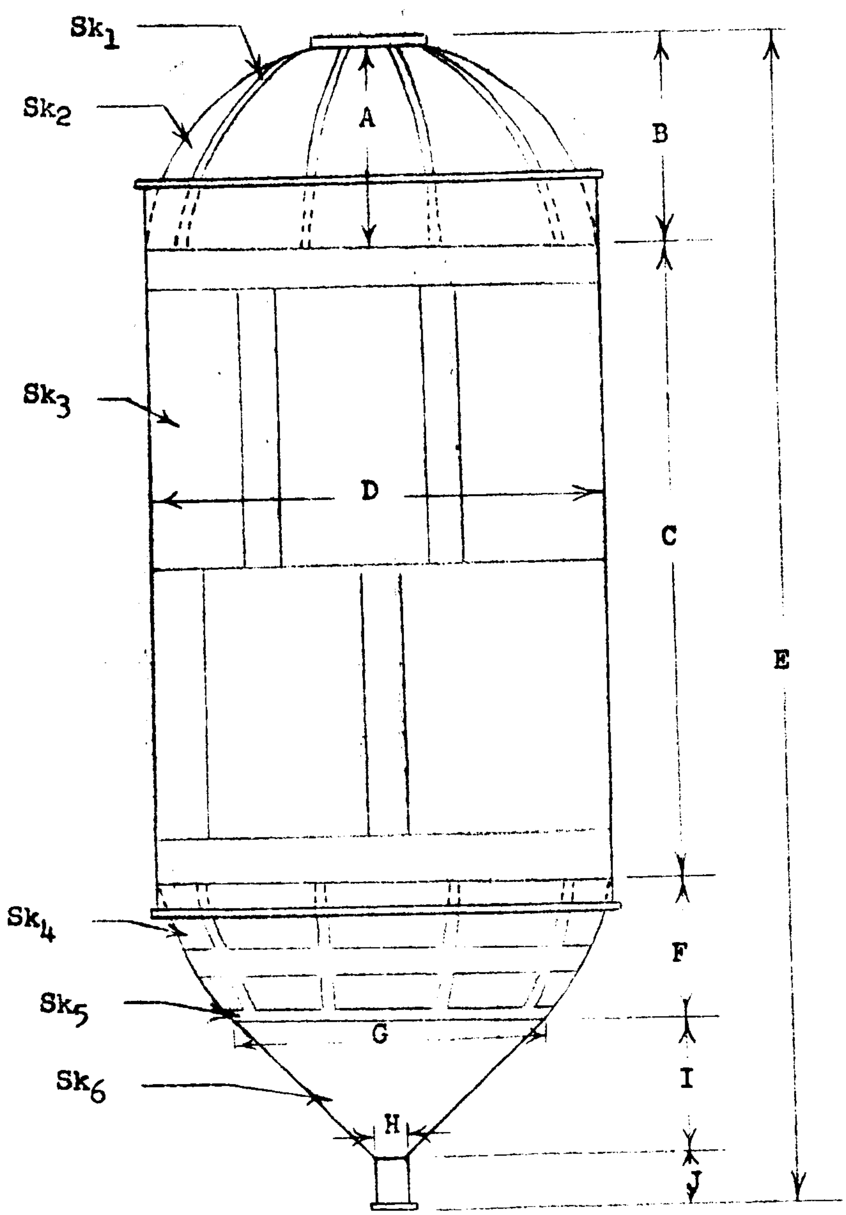
For fabrication the same jigs and tooling used for aluminum and steel vessels were used for titanium, with minor modifications. All welding was TIG, argon flooded for shielding, no filler, using high heat input and a speed of 12 inches per minute. The entire welding was accomplished by one man in approximately three weeks total time. Welds were x-ray inspected.

The cylinder section was constructed from 0.025 inch sheet, 36 x 96 inches. Longitudinal welds were staggered every 18 inches around the circumference. No stretch forming was needed. The sheets were simply draped over the wooden form and welded. A wheel type jig was designed to make the circumference welds. A channel was machined in its wall to carry gas to the weld.

The top and bottom closures are hemispheres which transition through a 45° cone to the tank cylinder. The hemispheres consist of 0.018 inch gauge cone trapizoidal sections welded together to form an orange peel pattern. Stress analysis indicated that the individual sections could be tapered in thickness to save weight. They were chemmilled to a taper from 0.018 to 0.014 inch. The sections were then stretch formed to shape and size in a heated die fixture at about 1300°F, followed by a stress relief at 1000°F and a descaling and pickling. Good joint fit up and uniform clamping were accomplished through magnetic hold-downs under the sheet sections and steel keepers directly above the hold-downs on the top of the sheet. The entire weld zone was shielded with argon.

Titanium has complete compatibility with liquid hydrogen and is noted at temperatures from -423°F to +200°F. The properties of 6Al-4V Titanium are included in Appendices "H."

Following is a sketch of the titanium test tank which is used to demonstrate tank dimensions and skin thickness at various locations. In addition a chart is provided to determine the volume of liquid hydrogen at varous points in the test tank during operating conditions. These volumes were calculated at ambient and at liquid hydrogen temperatures in addition to the operating pressures which were required for this program.



Tank Dimensions

Symbol	Inches
A	46.20
B	46.20
C	192.00
D	92.40
E	308.10
F	29.69
G	66.23
H	12.50
I	27.19
J	12.93

Skin Thickness

Symbol	Inches
Sk_1	0.018
Sk_2	0.014
Sk_3	0.025
Sk_4	0.014
Sk_5	0.018
Sk_6	0.025

Figure 1

6Al-4V TITANIUM TEST TANK
DIMENSIONS AND SKIN THICKNESS

	TEMPERATURE, °F					
	68 °F	-423 °F				
	PRESSURE, PSIA					
Station	12	12	20	30	40	50
308.01	7371.80	7336.40	7351.10	7369.50	7387.90	7406.40
304.01	7362.00	7326.70	7341.30	7359.70	7378.10	7396550
300.01	7333.90	7298.70	7313.30	7331.60	7349.90	7368.30
296.01	7289.10	7254.10	7268.60	7286.80	7305.00	7323.30
292.01	7229.50	7194.80	7209.20	7227.20	7245.30	7263.40
288.01	7156.60	7122.30	7136.50	7154.30	7172.20	7190.20
284.01	7072.50	7038.60	7052.60	7070.30	7088.00	7105.70
280.01	6978.70	6945.20	6959.10	6976.50	6993.90	7011.40
276.01	6876.90	6843.90	6857.60	6874.70	6891.90	6909.20
272.01	6768.90	6736.40	6749.90	6766.80	6783.70	6800.60
268.01	6656.60	6624.60	6637.90	6654.50	6671.10	6687.60
261.81	6477.70	6446.60	6459.50	6475.70	6491.90	6508.10
69.81	904.05	899.71	901.51	903.76	906.02	908.29
65.61	782.46	778.70	780.26	782.21	784.17	786.13
61.61	668.51	665.30	666.63	668.30	669.97	671.64
56.61	504.82	502.40	503.40	504.66	505.92	507.19
49.61	355.04	353.34	354.04	354.93	355.82	356.71
45.61	256.81	264.53	265.06	265,73	266.39	267.06
41.61	188.11	187.21	187.58	188.05	188.52	188.99
40.12	160.84	160.07	160.39	160.79	161.19	161.59
35.00	104.23	103.73	103.94	104.20	104.46	104.72
25.00	41.53	41.33	41.41	41.51	41.62	41.72
15.00	15.97	15.89	15.92	15.96	16.00	16.04
12.93	14.53	14.46	14.48	14.52	14.56	14.59
7.68	5.45	5.42	5.43	5.44	5.46	5.47
.00	.00	.00	.00	.00	.00	.00

Note: All volumes in gallons (US).
Boulder atmospheric pressure was taken as 12 PSIA.

Figure 2

7000 GALLON TITANIUM TANK VOLUMES

5.0 EXTERNAL HEATING PROGRAM - The test runs numbers 16, 17, 18, and 22 required the application of external heat flux. The requirements for the first three of these runs was 450 BTU/ft^2/hr. Run 22 was made with an application of 900 BTU/ft^2/hr.

The radient heat reflector assembly which was used is located inside of the vacuum bell. This assembly is made up of sixteen (16) angular segements, each with its independently programmed Ignitron controller, capable of Q/A, T/T, and aerodynamic heating simulation control modes. These reflector bands are 100 inches in diameter and each is twelve (12) inches wide. Over 3400 clear quartz crystal infrared lamps are used to furnish heat to the test tank. During this program the lamps were four (4) inches from the test tank skin. The heating capability for the system is 3,000 KVA for five (5) minutes or 1,500 KVA continuous operation. The heat imput is controlled by heat rate computers which are located in the remote control room.

For this program the heating rate was determined by measuring the boil-off rate and converting this rate to heat imput.

The heat rate desired was quite low, and control in the Q/A mode was not practical as the curve follower error itself would have resulted in 40% error (or variation between heating tanks). It was determined that the heat imput could be controlled better by temperature sensing and limiting the voltage level so that the heating was nearly constant on any one heat lamp tank.

The temperatures are not that of the titanium tank wall, but that of a ribbon thermocouple element bonded to the tank wall. The thermocouple is electrically and thermally insulated from the tank wall. The thermocouple measures only its own temperature which is a function of the radient heat imput and the thermal conduction of the bonding agent. It is assumed that the emissivity and the bonding is the same on each of the control thermocouples.

The total heat imput is the product of the desired heat imput per square foot and the total sidewall area heated by the lamps. The skirt and transition zones of the test tank were not heated. The total heat imput included the following;

1. Radiant and connective heat transfer to the test tank walls.
2. Conduction through the skirt and connections from the vacuum bell.
3. Boil-off produced within the fill line to the test tank from the FUEL FLOW CONTROL VALVE. (Entirely vacuum jacketed)

The following pages contain calculations and graphical curves which were used to determine the proper applications of heat for this program.

Radiant Heat Calculations:

Test Specimen: 7000 gallon titanium tank
Requirements: Radiant heat imput controlled at (a) 450 BTU/Ft^2/HR. (b) 900 BTU/Ft^2/Hr. on the vertical sidewall of the test tank.

Wall Area:

$$A = 2\pi Rh$$
$$A = 2\pi(46.2\ in)(16\ ft)$$
$$A = 2\pi(46.2\ in)(194\ in)$$
$$A = 92.4\pi(194)$$
$$A = 17925.6\ \pi$$
$$A = 56286.38\ in^2$$
$$A = \underline{391\ ft^2}$$

Heat of Vaporization: (Compendium WADD Technical Report 60-56 Part 1)

$$Q_{VAP} = (214.8\ Cal/Mole)(Mole/2.016Gm)(453.6Gm/\#)(1BTU/252Cal)$$

$$Q_{VAP} = \underline{192\ BTU/\#}$$

The Specific Heat:
The specific heat (C_p) of hydrogen gas, approximately, from 100°R to 120°R is constant at $\underline{2.50\ BTU/\#\ °R}$

Total Radiant Heat Imput Rate:

$$Q_{im} = \frac{(450)(391)}{60} = 2933\ BTU/Min$$

Heat Imput Calculations v.s. Boiloff:

$$Q_{im} = Q_{VAP} + Q_{gas}\Delta T$$

$$\dot{m} = \frac{Q_{im}}{Q_{VAP} + C_p \Delta T}$$

Assume equilibrium conditions at 15 psia and saturated liquid.

(A) 450 BTU/Ft^2/Hr
Requirements:
Wall Area 391 ft^2
450 BTU/Ft^2/Hr
Q_{im} 2933 BTU/Min
Q_{VAP} 192 BTU/#
C_p 2.50 BTU/#°R

For $T_v = 95°R$ $\quad \Delta T = 95-35 = 60°R$

$$\dot{m}\ \#/Min = \frac{Q_{im}}{QVAP + C_p \Delta T} = \frac{2933\ BTU/Min(\#)}{192BTU/\# + 250\ BTU/\#°R(60°R)}$$

$$= \underline{8.89\ \#/Min}$$

Reslutant Boiloff $= (8.89\ \#/\text{Min})\left(\frac{100\text{ft}^3}{0.56\#}\right)\left(\frac{95}{520}\right) = 290\ \text{ft}^3/\text{Min}$

For $T_v = 60°R$ $\Delta T = 25°R$

$$\frac{2933\ \text{BTU/Min}\ (\#)}{192\ \text{BTU/\#} + 2.50\text{BTU/\#°R}(25°R)} = 11.5\ \#/\text{Min}$$

$$(11.5\ \#/\text{Min})\left(\frac{100\ \text{ft}^3}{0.56\ \#}\right)\left(\frac{60}{520}\right) = 254\ \text{ft}^3/\text{Min}$$

For $T_v = 35°R$ $\Delta T = 0°R$

$$\frac{2933\ \text{BTU/Min}\ (\#)}{192\ \text{BTU/\#} + 2.50\ \text{BTU/\#°R}} = 15.05\#/\text{Min}$$

$$(15.05\#/\text{Min})\left(\frac{100\text{ft}^3}{0.56\#}\right)\left(\frac{35}{520}\right) = 194\ \text{ft}^3/\text{Min}$$

For $T_v = 140°R$ $\Delta T = 105°R$

$$\frac{2933\ \text{BTU/min}\ (\#)}{192\ \text{BTU/\#} + 2.50\text{BTU/\#°R}(105°R)} = 6.45\ \#/\text{min}$$

$$(6.45\ \#/\text{min})\left(\frac{100\text{ft}^3}{0.56\#}\right)\left(\frac{140}{520}\right) = 310\ \text{ft}^3/\text{min}$$

(B) 900 BTU/Ft²/Hr.

$$Q_{in} = \frac{(900)(391)}{60} = 5865\ \text{BTU/min}$$

For $T_v = 35°R$ $\Delta T = 0°R$

$$\frac{5865\ \text{BTU/min}\ (\#)}{192\ \text{BTU/\#} + 2.50\ \text{BTU/\#°R}\ (0°R)} = 31.6\ \#/\text{min}$$

$$(31.6\#/\text{min})\left(\frac{100\ \text{ft}^3}{0.56\ \#}\right)\left(\frac{35}{520}\right) = 380\ \text{ft}^3/\text{min}$$

For $T_v = 60°R$ $\Delta T = 25°R$

$$\frac{5865\ \text{BTU/min}\ (\#)}{192\ \text{BTU/\#} + 2.50\ \text{BTU/\#°R}\ (25°R)} = 23.0\ \#/\text{min}$$

$$(23.0\ \#/\text{min})\left(\frac{100\ \text{ft}^3}{0.56\#}\right)\left(\frac{60}{520}\right) = 474\ \text{ft}^3/\text{min}$$

For $T_v = 100°R$ $\Delta T = 65°R$

$$\frac{5865 \text{ BTU/min } (\#)}{192 \text{ BTU/\#} + 2.50 \text{ BTU/\#°R } (65°R)} = 16.6 \text{ \#/min}$$

$$(16.6)\left(\frac{100 ft^3}{0.56 \#}\right)\left(\frac{100}{520}\right) = 570 \text{ ft}^3\text{/min}$$

For $T_v = 140°R$ $\Delta T = 105°R$

$$\frac{5865 \text{ BTU/min } (\#)}{192 \text{ BTU/\#} + 2.50 \text{ BTU/\#°R } (105°R)} = 12.9 \text{ \#/min}$$

$$(12.9\text{\#/min})\left(\frac{100 ft^3}{0.56\#}\right)\left(\frac{140}{520}\right) = 622 \text{ ft}^3\text{/min}$$

For $T_v = 50°R$ $\Delta T = 15°R$

$$\frac{5865 \text{ BTU/min } (\#)}{192 \text{ BTU/\#} + 2.50 \text{ BTU/\#°R } (15°R)} = 25.6 \text{ \#/min}$$

$$(25.6 \text{ \#/min})\left(\frac{100 ft^3}{0.56\#}\right)\left(\frac{50}{520}\right) = 440 \text{ ft}^3\text{/min}$$

For $T_v = 80°R$ $\Delta T = 45°R$

$$\frac{5865 \text{ BTU/min } (\#)}{192 \text{ BTU/\#} + 2.50 \text{ BTU/\#°R } (45°R)} = 19.2 \text{ \#/min}$$

$$(19.2 \text{ \#/min})\left(\frac{100 ft^3}{0.56 \#}\right)\left(\frac{80}{520}\right) = 527 \text{ ft}^3\text{/min}$$

STABILIZED VENT FLOW RATE V.S. VENT GAS TEMPERATURE

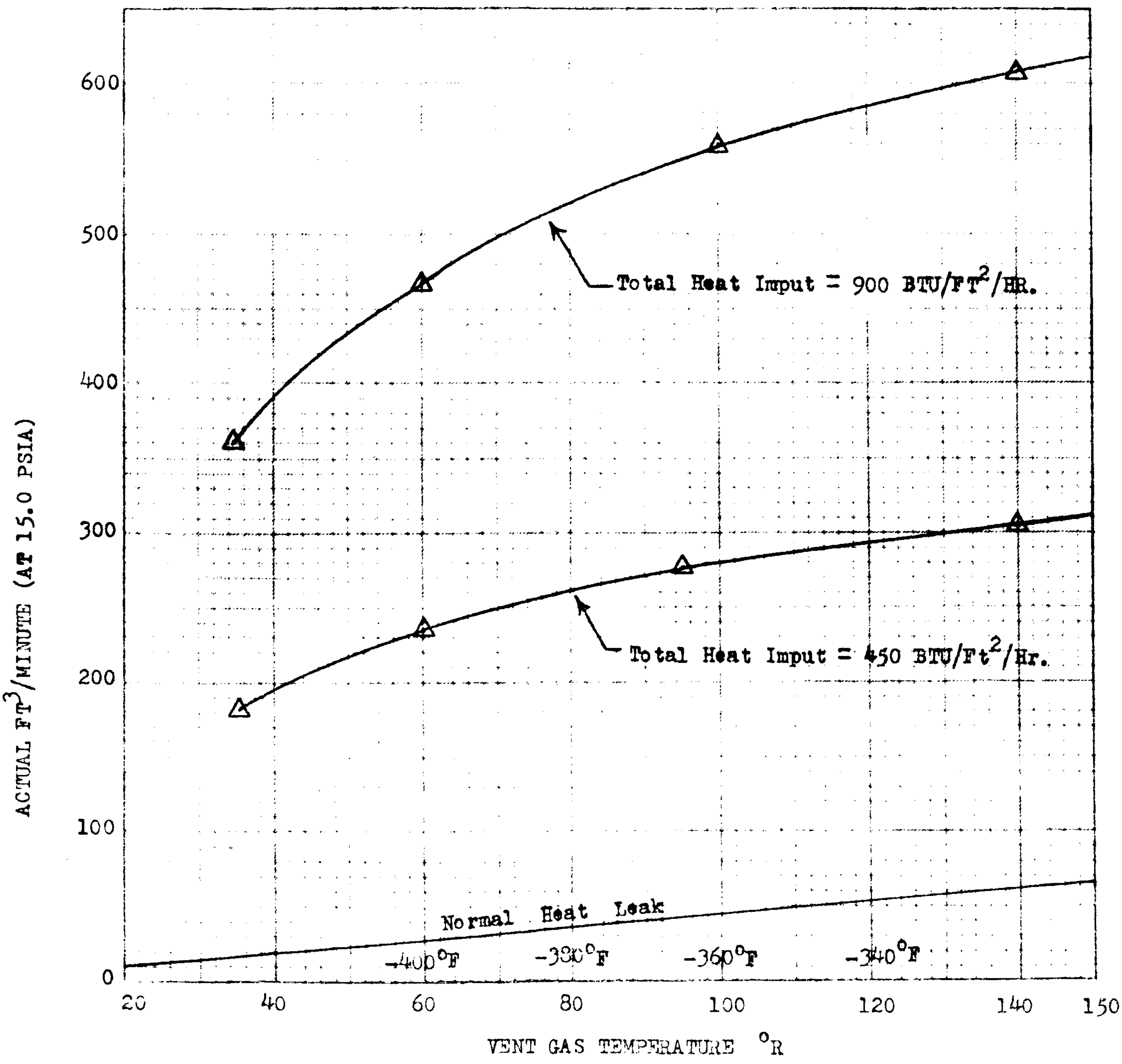


Figure 3

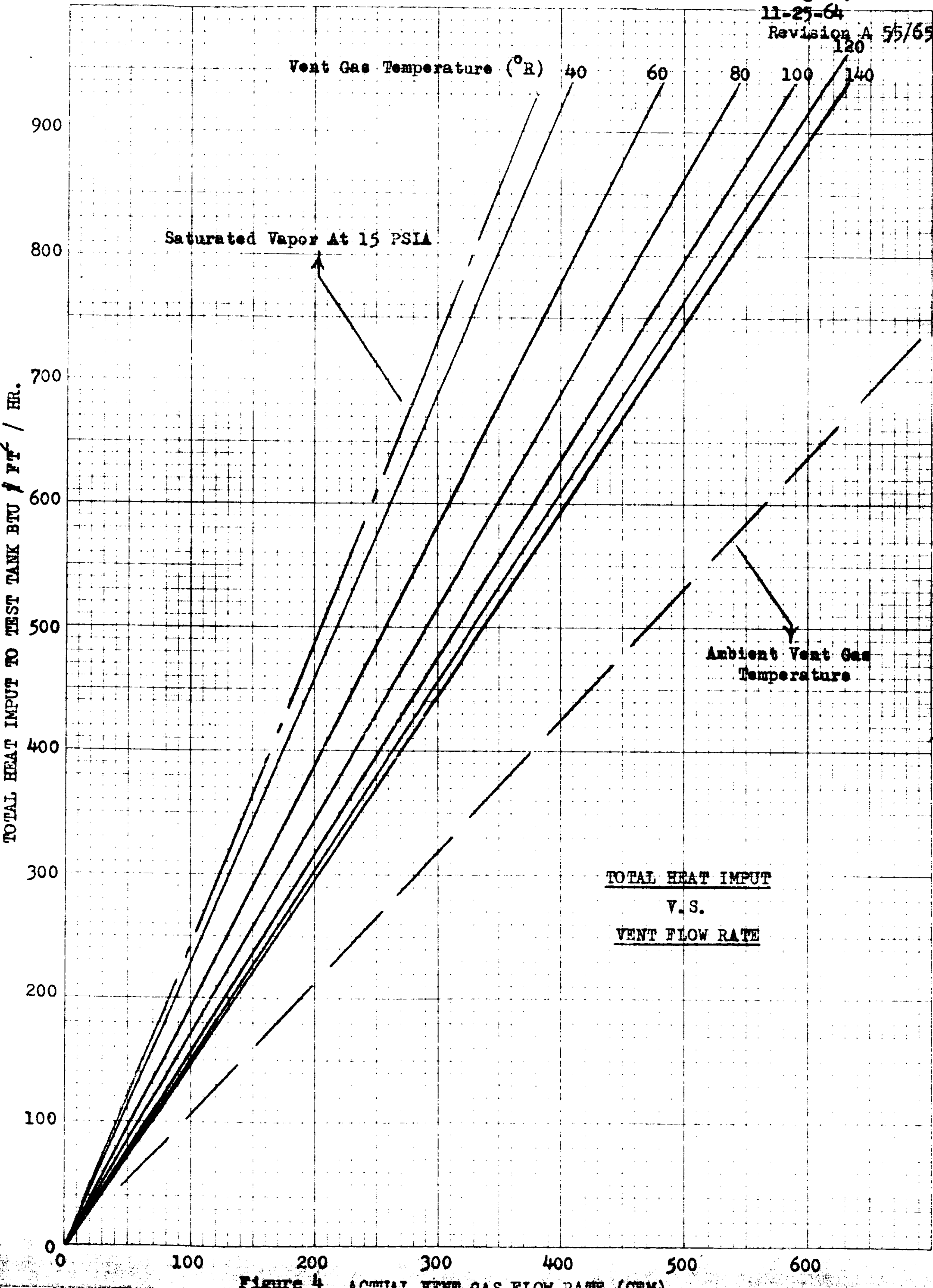

Vent Gas Temperature (°R)
40
60
80
100
120
140
Saturated Vapor At 15 PSIA
Ambient Vent Gas Temperature
TOTAL HEAT IMPUT
V. S.
VENT FLOW RATE
TOTAL HEAT IMPUT TO TEST TANK BTU / FT² / HR.
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
ACTUAL VENT GAS FLOW RATE (CFM)

Figure 4

6.0 LIQUID HYDROGEN GAS DIFFUSER - The pressurization and pre-pressurization gases comming into the test tank were distributed through a screen diffuser at the top of the test tank. The purpose of this diffuser was to minimize the inlet velocity and disturbances.

The diffuser used for this program was fabricated from 304 stainless steel. The screen was of 26 gage perforated stainless sheet with 0.033 inch diameter holes on 1/18 inch centers. These holes were staggered. Following are the calculations of the diffuser screen openings and the screen hole pattern:

0.033" diameter holes on 1/18" centers staggered.

Area of screen is: $A = \pi(R_1 + R_2)\sqrt{h^2 + (R_1 + R_2)^2}$

$$A = \pi(3.15 + 3.95)\sqrt{(2.0)^2 + (0.80)^2}$$

$$A = \pi(7.10)\sqrt{4.64}$$

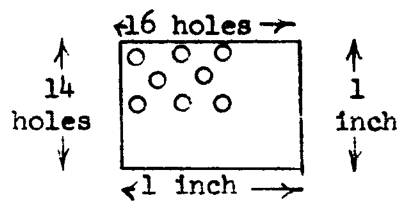
$$A = 48.2 \text{ in}^2$$

Total area of openings:

$$a = (0.033)^2 \frac{\pi}{4} (14)(16)(48.2)$$

$$a = 9.22 \text{ in}^2$$

Screen H ole Pattern



Diffuser Gas Velocity Cur ve

The following performance curve was made to show the gas velocity versus th mass flow for various temperature pressurant gas. The broken lines were added to show the effect of the higher tank pressure on the mass flow rate. A second scale was included for the mass flow rate of helium gas.

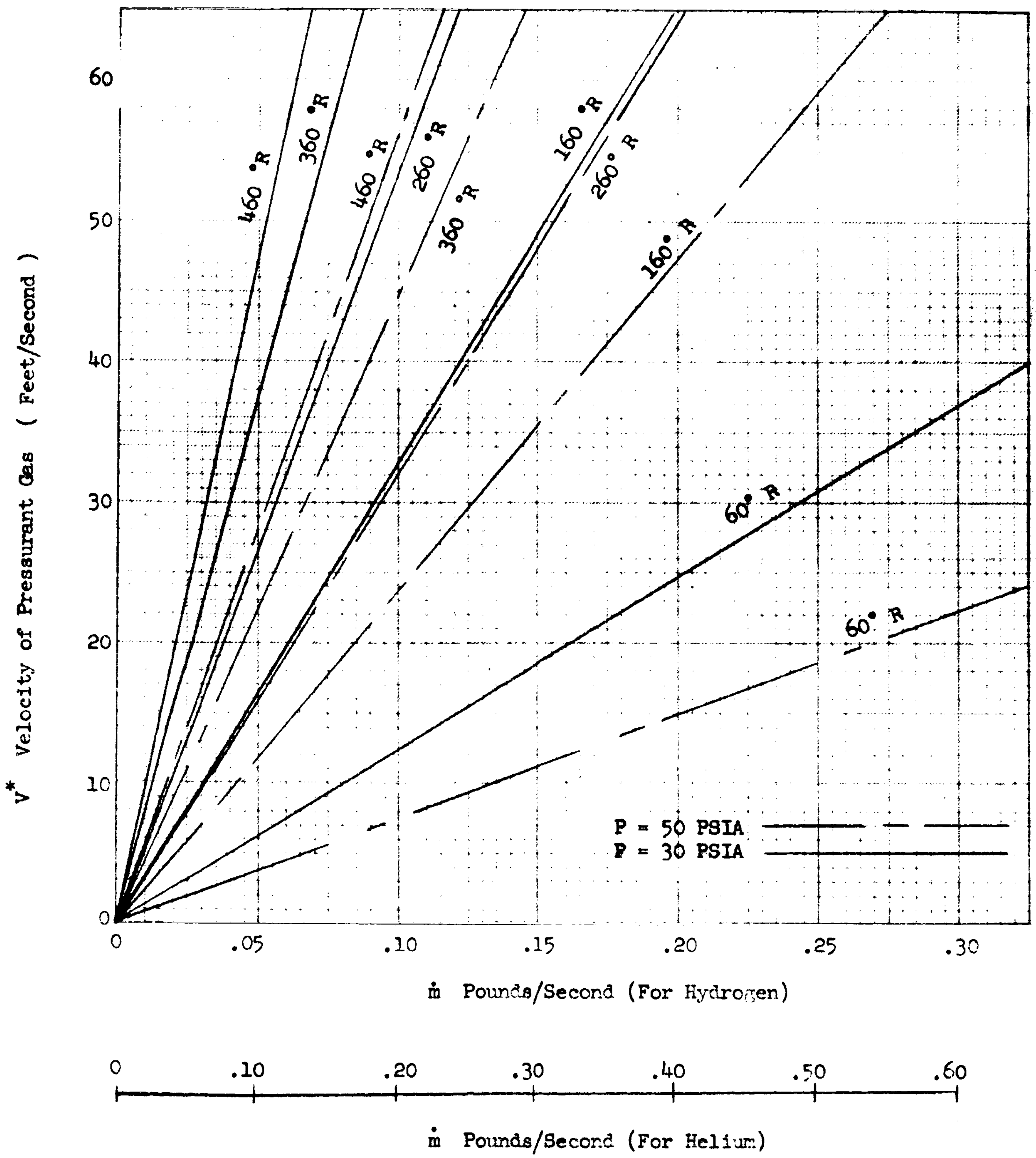
If the assumption is made that the volumetric flow of the pressurant gas must equal the volumetric flow of the liquid, the V* indicates the flow rate for a 40 second drain time.

The formula used fro the plot is: $\dot{m} = \frac{VPA}{RT}$

where: $\dot{m}$ = mass flow rate (pounds/second)
V = gas velocity (feet/second)
P = static pressure (psia)
A = total opening area in screen (in^2)
R = gas constant (feet/°R)
T = gas temperature (°R)

PERFORMANCE OF DIFFUSER

ON PRESSURIZATION LINE OF THE 7000 GALLON TEST TANK



V* = Velocity of gas with no heat transfer during 400 second drain.

Figure5

LIQUID HYDROGEN GAS DIFFUSER

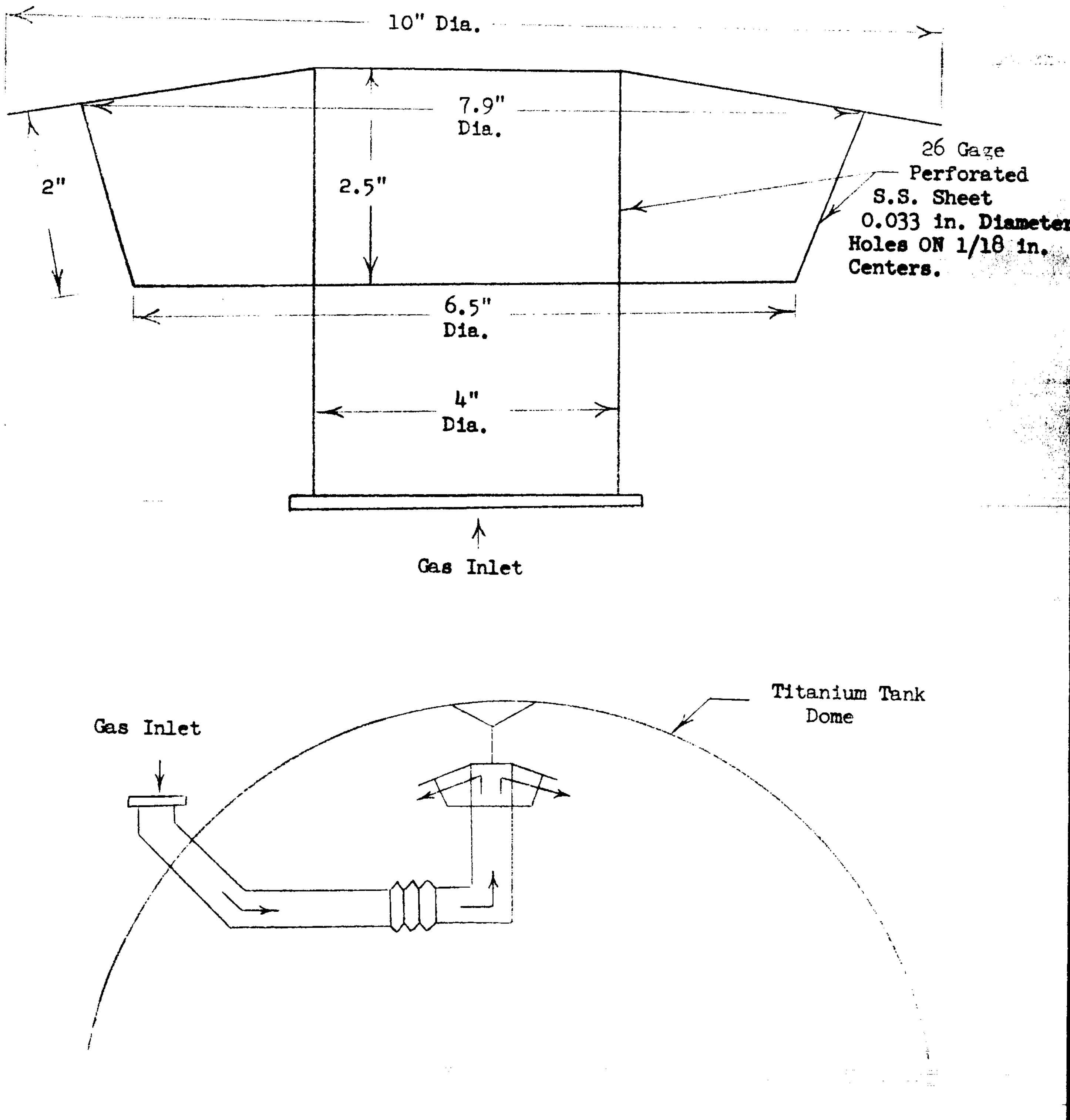


Figure 6 - LIQUID HYDROGEN GAS DIFFUSER

also insignificant. Therefore, setting $Q_k = Q_r = 0$ the energy balance equation reduces to:

$$Q_s = Q_c$$

This equation when written in terms of the temperature difference and assuming the gas and thermocouple parameters are constant shows that the time constant τ, is the time interval required for the junction to respond to 63.2 % of the step change in temperature of the media surrounding the couple. The time constant τ, is defined by:

$$\tau = \frac{\rho_w C_w V}{hA} \qquad \text{where}$$

ρ_w = density of the thermocouple wire

C_w = specific heat of the thermocouple wire

V = volume of the thermocouple wire

A = surface area of the thermocouple wire

h = heat transfer coefficient which is further defined as:

$$h = \frac{Nu\ Kg}{D} \qquad \text{where}$$

D = diameter of the wire

Assuming a gas velocity of 5 feet per second and solving the above equation for τ, resulted in time constants of 0.149 for hydrogen gas and 0.817 for nitrogen gas under the conditions of these tests. The actual velocity of the convection currents in the experiment were not measured and the five feet per second was arbitrarily taken in order to define the response parameters.

A step function of temperature in a non-flowing gas requires that the sensor be moved from one temperature region to another or that the sensor be conditioned to an "artificial" temperature in place in the reference gas. It was desired that the ullage gas be as undisturbed as possible and rapid movement between regions would produce both gas velocityand higher than normal initial response. The conditioning may be done by heating or cooling the sensor to a non-equilibrium temperature. This had been done previously by passing a current through the sensor to heat it to an unknown temperature but this involves switching the sensor from a voltage source to a galvanometer and the initial response is lost during the switching time. After consideration of the actual test conditions it was decided to condition the sensor in the saturated liquid, move it to a second position in the warmer ullage gas several inches above the liquid. The stratification was found to be extremely stable in a closed dewar and provided excellant thermal conditions. This also simulated draining of a test liquid to

7.0 FAST RESPONSE THERMOCOUPLE DEVELOPMENT - The thermocouple development program was initiated after an unfruitful search for a suitable thermocouple to measure ullage gas temperatures. The tests required a temperature sensor with a time constant of two seconds or less in hydrogen gas at two atmospheres pressure and cryogenic temperatures. Commerically available sensors of the resistance type were not considered because of the problems introduced by long instrumentation leads (60 feet) and also relatively high mass of the sensor element. Most time response data on temperature sensors is for high heat capacity fluids or for gases at relatively high velocities. Previous work indicated the sensitivity of thermocouples fabricated from small diameter wire and work began to optimize the design and determine the time constant for these specific conditions.

In order to obtain a fast response from a temperature sensor the heat capacity of the sensing element must be small in relation to the heat transfer to the element. Considering the heat capacity and thermal conductivity of low density gases it is obvious that a sensor element must be made with as little mass as possible. Also, the element must be thermally isolated from its supports. The first of these requirements is met by a small diameter thermocouple wire as the only mass involved is the mass at the junction of the dissimilar metals. The second requirement is met by making the leads of sufficient length that the heat conduction down the leads is small and assuming that the leads adjacent to the junction are subjected to the same thermal conditions. Other sensors were considered but were found to massive for fast response in low density gases. The mounting requirements were generally massive and too close in thermal proximity to be considered acceptable.Platinum wire resistance probes were considered but require a four-wire lead system to eliminate the error due to lead resistance changes. Also the sensor element "averages" the temperature between the sensor wire supports, which is affected to a considerable degree by heat transfer to the supports. It is obvious that the smallest thermocouple wire used will give the fastest response time. This program was restricted at the onset to a wire size considered large enough to withstand gas velocities up to 30 feet per second.

The rate of response of a thermocouple to a step change in the temperature of the surroundings is essentially a heat transfer problem. The energy balance of the thermocouple junction may be written as:

$$Q_r + Q_k + Q_c = Q_s \qquad \text{where:}$$

Q_r is the rate of heat transfer from enviroment to the junction by means of radiation.

Q_k is the rate of conductive heat transfer.

Q_c is the rate of convective heat transfer (the junction is assumed to have a finite length, for practical purposes includes segements of the wires of finite length).

Q_s is the rate at which heat is stored in the junction.

For purposes of simplification we will assume the thermocouple to be cylindrical and of sufficient length that Q_k becomes insignificant. As the absolute temperature of the radiating surfaces are relatively low, Q_r is below a sensor which leaves the sensor wetted and the resultant "drying" time of the sensor was also of interest for this program. After the sensor is moved to the gas space the wire dries off, during which the sensor remains stable at the saturated liquid temperature. The start of warmup is assumed to be the point at which the sensor is no longer cooled by the vaporizing liquid. This point can be used as zero time for the response time in gas only. The response time presented in the data includes this "drying" time which is a function of shape, orientation, and wettability of the couple as well as the heat of vaporization of the liquid.

The cryostat, Figure 9, used for the testing program was a 35-liter Hoffman liquified gas dewar. Extensive modifications were incorporated, which consisted of a movable travel rod, a set of limit switches, four liquid level indicators, and a reference probe. Fixtures were installed to enable fill, vent, and pressurization procedures. A pressure switch was utilized in order to calibrate thermocouples under pressurized conditions.

Using these systems and the supporting test equipment as specified in Figure 10, the apparatus allowed for the fast response testing and calibration of 45 production type sensors in addition to many experimental models.

The procedure used to perform the fast response thermocouple tests was conducted in the following manner. The cryostat was filled with the desired test media until the No. 2 liquid sensor indicated a covered condition. Both the test probe and the reference probe were then immersed in the liquid and allowed a five-minute stabilization period. At the conclusion of five minutes the millivolt output for both probes were read and recorded. Both probes were then raised to a gaseous media and the above stabilization time repeated. The millivolt output of both probes is then again read and recorded. At this time the test probe is lowered into the liquid and allowed five additional minutes to stabilize. The recorder is then started and the test probe is raised to a gaseous media. Each thermocouple was tested for ten runs and the average response time then evaluated.

The first type test probe which was tested was a teflon bracket slingshot thermocouple that NASA has used satisfactorily in liquid oxygen. The response time for these probes was very poor and efforts were concentrated on the fabrication of various other types, each expressing some of the ideas which it was felt might be influencing the response of the thermocouples. Following is a list of the ideas which were derived and tested:

1. The thickness of the teflon slingshot frame.

   Results: The mass definitely increased the response time considerably.

2. A slingshot frame fabricated with 18 gauge culcon thermocouple wire.

   Results: Much faster response and provided basis for the final production-type probe.

3. Dimensions of slingshot frame.

Results: One, two and three-inch square frames were tested, with the three-inch model producing a 1.1 average time constant. In comparison the average time constants were 2.0 and 5.0 for the two-inch and one-inch models respectively.

4. Thermocouple junction weld.

Results: The junctions of thermocouples of good response were broken and rewelded. The response time of the re-welded thermocouples was within 2% of the original concept. It was noted the thermocouples with excessive wire protruding past the weld provided slow response times.

5. The location of welds on lead wires in relation to the frame.

Results: On the teflon frames, a weld on the outer edge of the probe rather than on the inside edge resulted in a 10% increase in response time.

6. Angle formed by the thermocouple junction.

Results: Thermocouples with the junction formed two inches above the vertical arms of the frame provided considerably faster response than junctions forming a larger angle.

7. Relation of the thermocouple to the horizontal during testing.

Results: Thermocouples tilted to a 30° to 45° angle above the horizontal during testing provided approximately a 25% decrease in response time.

8. Effect of insulation and varnish on the thermocouple wire.

Results: The bare wire provided a much faster response time and further testing revealed that the removal of the insulation from the arms of the frame resulted in an additional 8% to 10% time constant decrease.

9. Cleaning of the thermocouple wire at the junction.

Results: A slight response change was evident.

10. Travel of probe being removed from liquid.

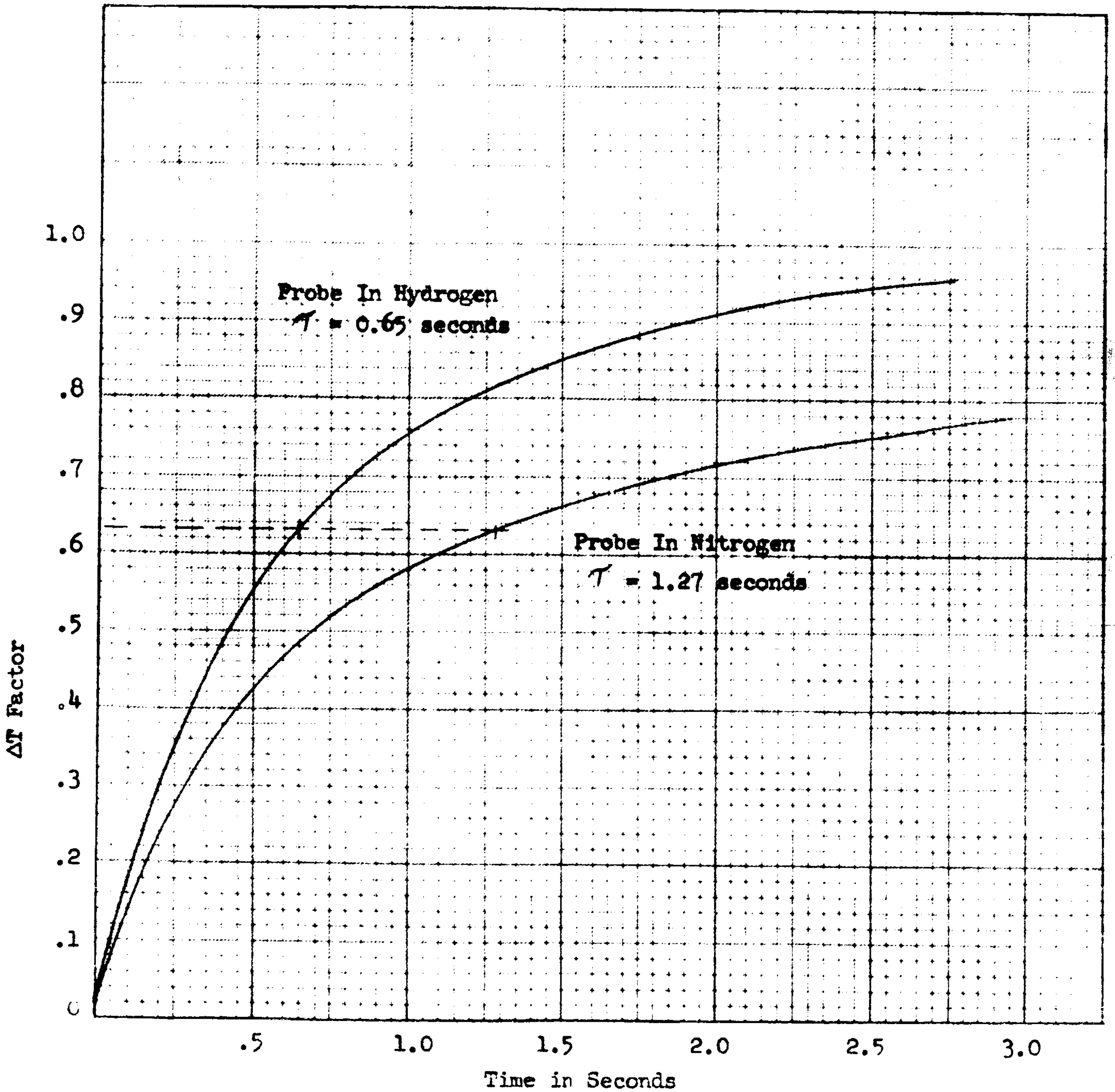
Results: During testing the probe traveled approximately eleven (11) inches. For the most satisfactory response the time, for the probe to travel this distance, was 0.5 second to 0.9 second.

At the conclusion of testing the thermocouple, as demonstrated in Figure 8, was selected, based on these results.

FINAL RESULTS

At the conclusion of the test program forty-five (45) thermocouples were constructed based on the results of the preliminary models. Response tests and calibrations were made on each of these thermocouples. Calibrations indicated an output versus temperature function very close to that of Powell, Caywood and Bunch although there was a definite offset from the referenced curve. The response of all thermocouples was in excess of 63.2% in two (2) seconds for a change from liquid nitrogen to gas. The time constant, for the response in nitrogen gas (subtracting the "drying" time) is approximately 1.10 seconds. The time constant for the same response in hydrogen gas was approximately .20 second. The sensor in the outflow line was subjected to gas velocities of about fifty (50) feet per second during each of the 35 cool-downs and liquid velocities up to thirty-two (32) feet per second. This sensor failed on the 35th fill operation. All other thermocouples lasted for the duration of the tests.

Further information as to this test program is available in a paper entitled, "Fast Response Thermocouples for Measurement of Temperatures in Cryogenic Gases," by C. C. Robinson, T. Bielawski and A. R. Lowrie. This paper was presented at the National Aeronautics and Space Administration Liquid Hydrogen Symposium in Huntsville, Alabama on January 19 and 20, 1965.



$$\Delta T = \frac{\text{Thermocouple Temperature - Liquid Temperature}}{\text{Gas Temperature - Liquid Temperature}}$$

Figure 7

TYPICAL PRODUCTION THERMOCOUPLE RESPONSE CURVE

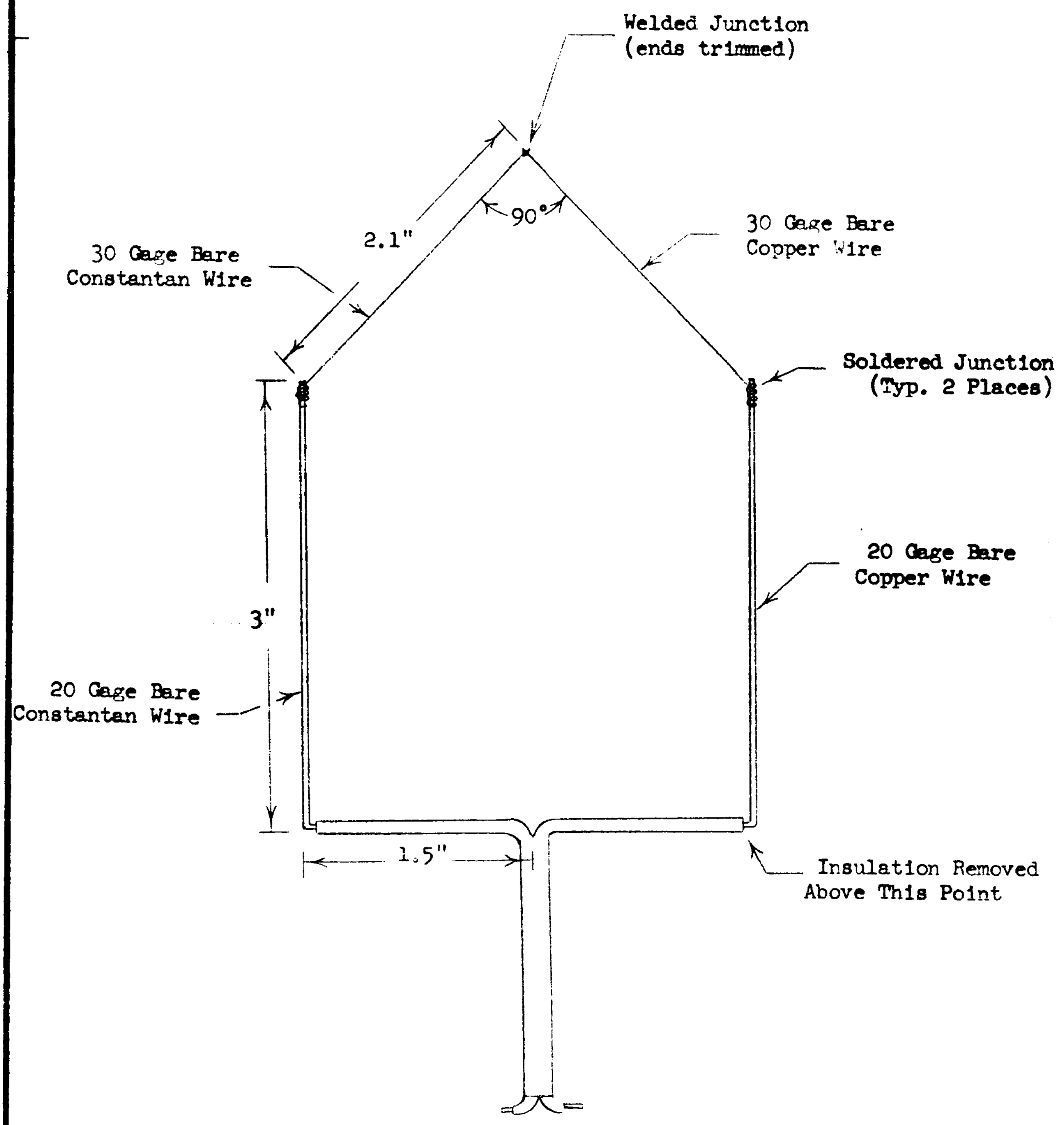


Figure 8
FAST RESPONSE THERMOCOUPLE

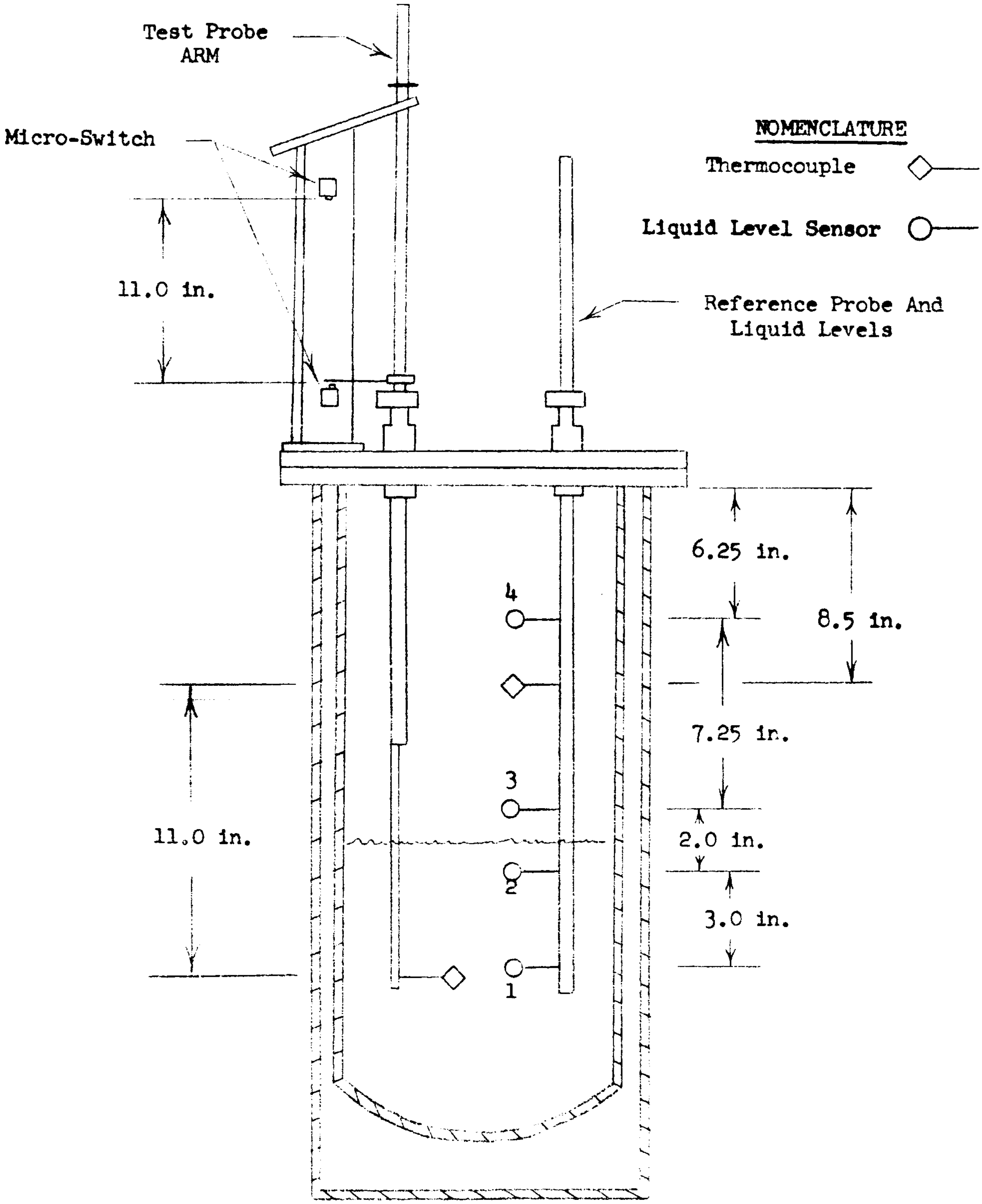


Figure 9

THERMOCOUPLE CRYOSTAT

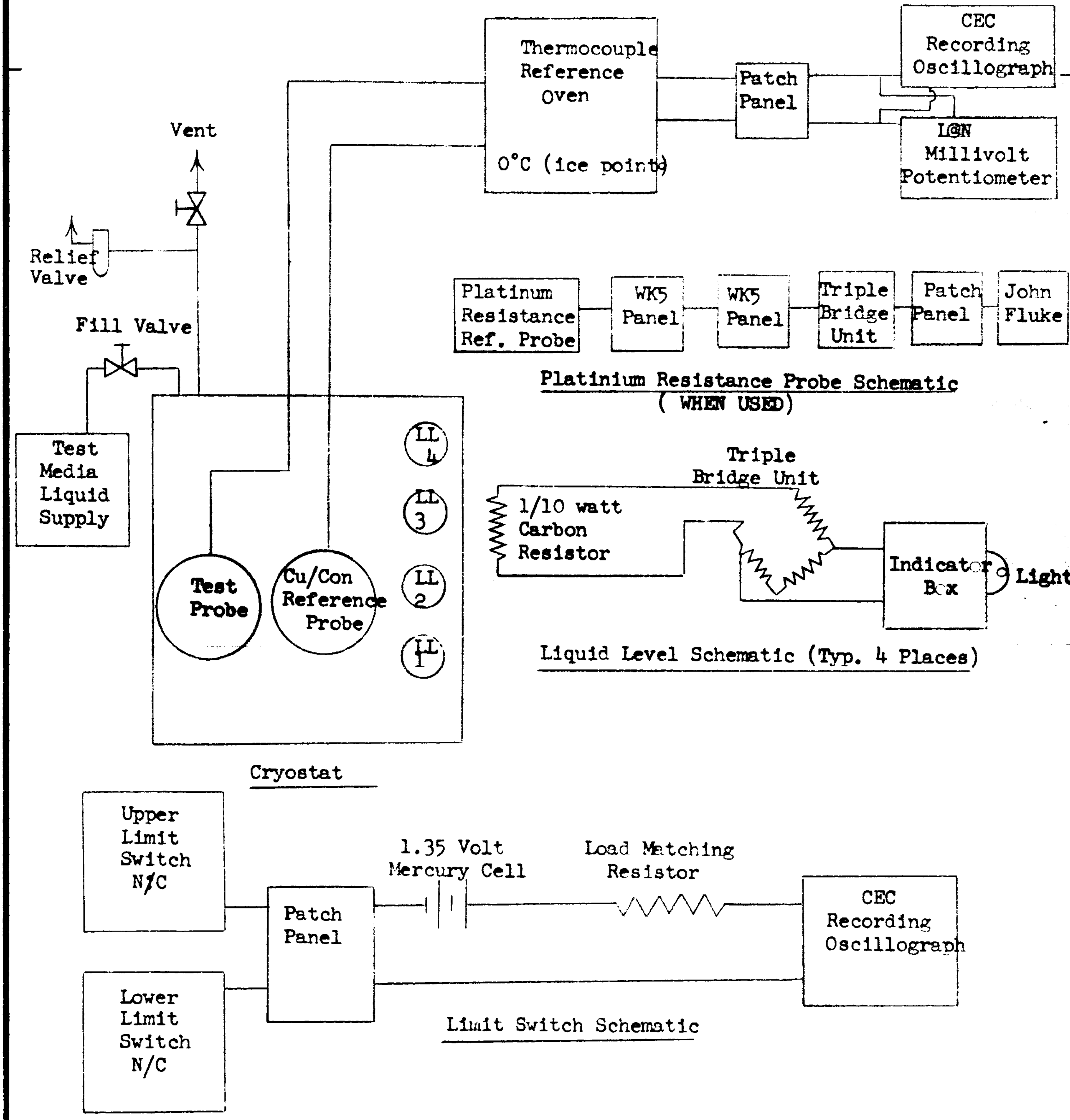


Figure 10

THERMOCOUPLE TEST SETUP SCHEMATIC

8.0 DATA PROGRAM

The data on this test was taken in three separate systems. The first system was sixteen (16) bristol recorders which were used to measure skin temperatures. These thermocouples were patched through a 150° reference oven and wired directly to the recorders. The system is a permanent type and the recorders were built specifically for this purpose. The paper and the recorders were scaled in order to enable data reduction for the program.

A brush events recorder was used to supply the liquid level indications as are called out on the Instrumentation Channel Assignments (Appendix G). In conjunction with the liquid level indicators, a switch trace of FFC (Fuel Flow Control Valve) was provided. The data on this recorder is of the go-no-go type. This is to say that there is either a trace or a blank. A trace is used to indicate a liquid condition while a blank will indicate the area is in a gaseous state. One-tenth (1/10) watt carbon resistors were used to pick up the liquid indication.

The third system was the data computer program which was written to enable Beech Aircraft Corporation to reduce data from the MTA magnetic tape through the use of the G-15D computer. Due to the large amount of time involved to print out this data, it was decided that the information would be transferred to compatible IBM tapes for data reduction on the National Bureau of Standards Digi-Data tape writer. The final typeout was in engineering units and decimal form, while the 98 channels of information were supplied once every 0.5 second.

The ninety-eight channels used in the computer program were deivided as follows:

Channel 1 - Time

The time is provided for relative timekeeping on the data and does not necessarily indicate test time. It runs freely until it reaches approximately 7200 at which time it resets and starts over. This could occur in the middle of a test run. Actual test start is ascertained by valve switch traces.

Channels 2 and 3 - Zero and Full Scale Respectively

The zero and full scale are used for checking the data system. The optimum values for these are zero = 0000 and full scale = 4800. As long as these do vary more than 50 counts there is no data problem.

Channels 4 through 43 - Germanium Thermometers

These channels provide the output from the germanium probes which read directly in degrees Kelvin. The probes had a log/log range between 20°K and 40°K with a separate calibration curve for each probe. The accuracy obtained with curve approximation was ±0.2°K between this range. An over range of a channel is indicated by a minus (-) sign as was the case of the germanium probes when the temperature reached 40°K plus.

Channels 44 through 83 - Fast Response Thermocouples

These channels provided a range of 20°K to 273°K. The calibration data indicated a ±2°F variation between all forty fast response thermocouples with a response time of less than 0.6 second for 63% of the total change. These probes all used a common calibration curve which was derived from average millivolt readings during individual thermocouple calibration. The accuracy was better than 1% in the range of these probes and since the reference over provided the largest error, yet was the best available, it was decided that a common curve could be used.

Channels 84, 85 and 86 - Temperatures (Linear)

These temperatures were for the buildup, prepressurization, and pressurization-vent gas. They were standard thermocouples with linear relationship to the physical phenomena. The readouts were in degrees Kelvin.

Channels 87, 88 and 89 - Pressures (Linear)

These pressures were for ullage, prepressurization, and pressurization gas. All readouts were in psia.

Channels 90, 91 and 92 - Flow Rates

These channels provided the pre-pressure, pressure-vent, and propellant flow rates. The gaseous flows were supplied in CFM, while the liquid flow was in GPM.

Channels 93, 94 and 95 - Valve Switch Traces

These channels indicated the position of the following valves. A reading of 0 to 75 indicates that the valve is closed, while a 150 to 5000 reading indicates an open position. The valves called out were (PV) pressurization valve, (FFC) fuel flow control valve, and (PPC) pre-pressurization control valve.

Channels 96, 97, 98 and 99 - Liquid Levels

These liquid levels were sensors No. 3, 10, 44 and 43 respectively. Readings of 0 to 75 indicate a liquid condition, while readings of 150 to 5000 indicate that the sensor is in a gaseous state.

The following is a sample of a printed data sheet demonstrating the reduced data as received from the Digi-Data tape writer.

BEECH TEST REPORT

Beech Aircraft Corporation — Environmental Test Laboratories

Document No.	Rev	Page
FR 13632	A	40.0

Issue Date	Revision Dates
11/25/65	"A" 5/5/65

Time = 1155.2 Zero Reference = 34 Full Scale Reference = 4817

Cnnl.	Temp.	Chnl.	Temp.	Cnnl.	Temp.	Chnl.	Temp.	Chnl.	Temp.
4	20.2	5	20.1	6	20.2	7	21.0	8	20.1
9	20.3	10	20.3	11	20.2	12	20.0	13	21.4
14	20.1	15	-41.0	16	-41.0	17	20.1	18	-41.0
19	-41.0	20	-41.0	21	-41.0	22	-41.0	23	-41.0
24	-41.0	25	-41.0	26	-41.0	27	-41.0	28	-41.0
29	-41.0	30	-41.0	31	-41.0	32	-41.0	33	-41.0
34	-41.0	35	-41.0	36	-41.0	37	-41.0	38	-41.0
39	-41.0	40	-41.0	41	-41.0	42	20.1	43	[illegible]
44	20.8	45	20.4	46	20.4	47	20.4	48	22.1
49	271.9	50	20.4	51	20.4	52	20.4	53	20.4
54	23.8	55	20.4	56	20.4	57	20.8	58	22.1
59	22.9	60	23.3	61	20.4	62	20.4	63	20.4
64	70.7	65	162.2	66	90.0	67	84.8	68	89.2
69	20.4	70	90.5	71	92.4	72	98.5	73	100.2
74	96.4	75	95.0	76	100.2	77	96.4	78	97.5
79	95.8	80	87.6	81	98.1	82	98.3	83	99.9
84	332.7	85	105.3	86	118.8	87	8.1	88	9.8
89	8.1	90	1.5	91	388.0	92	1065.0	93	3496.0
94	3542.0	95	46.0	96	120.0	97	4094.0	98	4094.0
99	4094.0								

9.0 <u>TEST RESULTS</u> - The following pages contain samplings of data taken from the magnetic tapes and the 30-channel events recordings. (Liquid Levels). While this information does not supply a detailed account of the test run, it does give an indication of some of the required operating parameters. Since data analysis was not required per contractual agreement, this report is not intended for that purpose but the Appendix "K" does include some of the finalized curves and plots which were supplied by NASA after data analysis.

A run sheet has been provided for test run no. 3, which contains only the liquid level sensor response. All data on themagnetic tapes was very erratic due to a timing problem and much of the data is questionable. The pre-pressurant and pressurant gas temperatures, the operating pressure, and the flow rate of propellant appeared within specifications. A closer analysis of this run could possibly supply some information, but a problem would exist as to just where in the test run the readings occurred.

The data for Test Run No. 8 is included up to the point of the tank rupture. Since this was the first 50 psia test run, there will not be a comparative source of data.

The following general information is pertinent to this test program:

(1) The liquid temperatures, which were determined by the germanium thermometers, only indicated between the ranges of 20°K and 40°K. Any temperatures which were warmer than 40°K still indicated this reading.

(2) The duration of the drain operation was estimated from the pressurization valve switch trace (PV) rather than from the fuel flow control valve (FFC) switch trace. The reason for this being that the response of the FFC valve was slightly slower and for testing purposes both valves were actuated simultaneously.

(3) The three pressurization transducers varied approximately 2 psi at stabilized conditions. This variation was slightly more during flow conditions.

(4) At the conclusion of each run the recorders were operated for 5 seconds after a 5-minute stabilization period.

(5) During Run No. 1 the pressurization and vent gas flow rate range was set at 750-1250 cfm. For all other runs the low range was at zero.

(6) Liquid level sensors 5 and 7 did not respond properly for any of the test runs.

(7) All vacuum pressure readings supplied in this program were from visual observation.

(8) The test tank external skin temperatures were supplied on the Bristol Temperature Recorders. The recorder speed was 2.5 inches per minute. Recordings were supplied to NASA.

(9) Channels that were disconnected from the commutator were called out on the following run sheets.

(10) Temperature variations for operating gases could be due to system conditions from the previous run. Several of the runs were conducted in a close proximity of time.

All liquid hydrogen used in this program was guaranteed 95% parahydrogen according to MIL Specifications P27201.

Run Number 1

Date Test Conducted: 31 July 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	100°F Hydrogen
Operating Pressure	30 psia
Pre-Pressurization Time	61.3 seconds
Stabilization Time	10.5 seconds
Drain Time	363.1 seconds
Ullage (Prior to Pre-Pressurization)	5% (App. 6998.9 Gallons)

Pre-Pressurant Gas Temperature

Time	Temperature	
T + 0	272.4°K	30.8°F
T + 10	283.4	50.6°F
T + 20	287.0	57.1°F
T + 30	287.0	57.1°F
T + 40	284.6	52.6°F
T + 50	283.4	50.6°F
T + 60	281.0	46.2°F
T + 61.3	281.6	47.2°F

Ullage Pressure at Completion of Pre-Pressurization 30.4 psia

Drain Operation

Time	Pressurant Temperature		Ullage Pressure
T + 0	198.2°K	-102.9°F	29.9 psia
T + 10	238.2	-30.9°F	30.7
T + 60	262.6	13.0°F	31.3
T + 110	263.6	14.9°F	31.9
T + 160	264.8	17.0°F	31.5
T + 210	267.4	21.7°F	31.1
T + 260	267.4	21.7°F	31.9
T + 310	269.9	26.2°F	32.2
T + 360	269.9	26.2°F	32.2
T + 363.1	269.9	26.2°F	32.2

Sensor Response

Sensor No.	Time (sec.)	Volume (Gal.)	Flow Rate (GPM)
48	Uncovered Prior to Start of Drain		

Sensor Response, Continued...

Sensor No.	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
48 to 44			
44 to 10	Response was not Correct		
10 to 3	267.6	4875.3	1093.1
3 to empty	65.0	1165.1	1078.8

After 5 Minute Stabilization

Ullage Pressure	31.5 psia	
Temperature at Diffused	262.9°K	13.8°F
Temperature at 150" Level	195.3°K	-108.1°F
Temperature at 30.81" Level	20.3°K	-423.1°F
Temperature at Outflow Line	38.2°K	-390.9°F

Run Number 2

Date Test Conducted: 21 August 1964

Pre-Pressurant Gas	0°F Helium
Pressurant Gas	0°F Hydrogen
Barometric Pressure	621.70
Operating Pressure	30 psia
Pre-Pressurant Time	79.2 seconds
Stabilization Time	8.5 seconds
Drain Time	400.4 seconds
Ullage (Prior to Pre-Pressurization)	5% (App. 6998.9 Gallons)

Pre-Pressurant Gas Temperature

Time	Temperature	
T + 0	263.9°K	15.4°F
T + 10	269.6°K	25.8°F
T + 20	263.6°K	14.9°F
T + 30	263.3°K	14.5°F
T + 40	267.1°K	21.1°F
T + 50	258.1°K	5.0°F
T + 60	248.5°K	-12.2°F
T + 70	262.3°K	12.7°F
T + 79.2	258.7°K	6.1°F

Ullage Pressure at Completion of Pre-Pressurization 32 psia

Drain Operation

Time	Pressurant Temperature		Ullage Pressure
T + 0	212.7°K	-76 6°F	32.1 psia
T + 10	231.9°K	-42.0°F	31.2 psia
T + 34	241.3°K	-25.2°F	31.3 psia
T + 59	244.1°K	-20.1°F	31.0 psia
T + 84	247.1°K	-14.7°F	30.9 psia
T + 109	248.1°K	-12.9°F	32.0 psia
T + 134	248.1°K	-12.9°F	31.3 psia
T + 159	250.2°K	-9.2°F	31.7 psia
T + 209	251.2°K	-7.3°F	31.8 psia
T + 259	249.8°K	-9.8°F	31.3 psia
T + 309	251.2°K	-7.3°F	31.3 psia
T + 359	252.2°K	-5.6°F	31.4 psia
T + 379	250.8°K	-8.0°F	31.8 psia
T + 389	252.5°K	-5.6°F	32.0 psia
T + 399	251.8°K	-7.8°F	31.7 psia
T + 400.4	252.2°K	-5.6°F	31.8 psia

Run Number 2, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
42 to 34	13.1	219.7	1014
34 to 22	19.7	339.9	1103
22 to 10	19.1	348.2	1101
10 to 9	40.1	696.5	1043
9 to 6	119.7	2039.4	1043
6 to 4	79.4	1393.0	1053
4 to 3	40.4	696.4	1038
3 to 2	38.4	695.4	1083
2 to 1	23.8	395.2	996
1 to Empty	5.6	74.5	797

Sensors No. 5, 7 and 8 did not respond properly.

Sensor Response During Pre-Pressurization

Sensor No.	Sensor out of Liquid (Seconds After Start of Pre-Pressurization)
46	1.6
44	7.2
43	16.2
42	1.0 (After Start of Drain)

After 5 Minute Stabilization

Ullage Pressure	30.7 psia	
Temperature at Diffuser	219.6°K	-64.2°F
Temperature at 150" Level	192.6°K	-112.3°F
Temperature at 30.81" Level	42.7°K	-382.6°F
Temperature in Outflow Line	50.7°K	-368.2°F

RUN NUMBER 3

Date Test Conducted: 20 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-100°F Hydrogen
Barometric Pressure	617.50
Operating Pressure	30 psia
Pre-Pressurization Time	60 seconds
Stabilization Time	9.2 seconds
Drain Time	399.5 seconds
Ullage (Prior to Pre-Press.)	5% (App. 6998.9 Gallons)

Sensor Response During Drain

Sensors	Time (Sec.)	Volume(Gal.)	Flow Rate (GPM)
34 to 22	18.8	339.9	1084
22 to 10	19.4	348.2	1073
10 to 9	40.6	696.5	1030
9 to 8	40.0	656.5	985
8 to 6	80.8	1392.9	1030
6 to 4	79.8	1393.0	1050
4 to 3	40.3	696.4	1035
3 to 2	37.9	695.4	1098
2 to 1	23.6	395.2	1010
1 to Empty	5.8	74.5	720

Sensor numbers 5 and 7 not responding properly.

Sensor Response During Pre-Pressurization

Sensor No.	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	1.4
44	2.7
43	4.8
42	7.6
34	12.2 (After Start of Drain)

Vacuum Readings

Start of Pre-Pressurization	40 Microns
End of Pre-Pressurization	1500 Microns
T + 6 seconds	2200 Microns
T + 400 seconds	2500 Microns

NOTE: The above data was taken from the Brush Recording. The timing on magnetic tape was not correct and data questionable. Following samples taken during run:

Pre-Press. Gas Temp.	287.6°K	58.1°F
Pressurant Temp.	204.1°K	-92.4°F

Run Number 4

Date Test Conducted: 21 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-200°F Hydrogen
Barometric Pressure	621.70
Operating Pressure	30 psia
Pre-Pressurization Time	64.6 seconds
Stabilization Time	8.9 seconds
Drain Time	403.6 seconds
Ullage (Prior to Pre-Pressurization)	5% (App. 6998.9 Gallons)

Pre-Pressurant Gas Temperature

Time	Temperature	
T + 0	185.4°K	-125.8°F
T + 10	138.0°K	-211.2°F
T + 20	126.5°K	-232.0°F
T + 30	127.6°K	-229.8°F
T + 40	137.0°K	-212.9°F
T + 50	139.0°K	-209.2°F
T + 60	136.4°K	-214.0°F
T + 64.6	134.9°K	-216.7°F

Ullage Pressure at Completion of Pre-Pressurization 31.7 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	221.5	-60.8	31.9
T + 10	193.5	-111.2	31.4
T + 20	182.5	-131.0	30.7
T + 45	166.3	-160.1	30.7
T + 70	160.4	-170.8	31.2
T + 95	158.6	-174.0	31.1
T + 120	154.9	-180.7	31.4
T + 170	154.9	-180.7	31.2
T + 220	154.5	-181.4	31.7
T + 270	155.4	-179.8	31.7
T + 320	154.9	-180.7	31.6
T + 370	155.8	-179.1	31.4
T + 388	154.5	-181.4	31.8
T + 398	154.0	-182.0	31.4
T + 402	155.4	-179.8	31.5
T + 403.6	153.5	-183.4	31.3

BEECH TEST REPORT

Run Number 4, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
43 to 42	1.9	25.5	807
42 to 34	12.5	219.7	1062
34 to 22	19.3	339.9	1060
22 to 10	19.4	348.2	1080
10 to 9	39.9	696.5	1045
9 to 8	39.9	656.5	1038
8 to 6	80.2	1392.9	1044
6 to 4	80.2	1393.0	1044
4 to 3	40.8	696.4	1021
3 to 2	38.5	695.4	1082
2 to 1	24.0	395.2	989
1 to Empty	5.7	74.5	798

Sensors 5 and 7 did not Respond Properly.

Sensor Response During Pre-Pressurization

Sensor No.	Sensors Out of Liquid (Seconds After Start of Pre-Pressurization)
46	1.7
44	6.3
43	1.3 (After Start of Drain)

Vacuum Bell Pressure

Pre-Pressurization	60 microns
Start of Drain	500 microns
Middle of Drain	500 microns

After 5 Minute Stabilization

Ullage Pressure	31.5 psia	
Temperature at Diffuser	143.3°K	-201.4°F
Temperature at 150" Level	140.8°K	-206.0°F
Temperature at 30.81" Level	43.0°K	-382.0°F
Temperature in Outflow Line	51.2°K	-367.3°F

Run Number 5

Date Test Conducted: 22 August 1964

Pre-Pressurant Gas	-300°F Helium
Pressurant Gas	-300°F Hydrogen
Barometric Pressure	620.50
Operating Pressure	30 psia
Pre-Pressurization Time	54.2 seconds
Stabilization Time	12.4 seconds
Drain Time	407.7 seconds
Ullage (Prior to Pre-Pressurization)	5% (App. 6998.9 Gallons)

Pre-Pressurant Gas Temperature

Time	Temperature °K	Temperature °F
T + 0	259.7	7.9
T + 10	223.0	-58.1
T + 20	198.6	-102.0
T + 30	163.1	-166.0
T + 40	130.2	-225.1
T + 50	105.3	-269.9
T + 54.2	92.1	-293.7

Ullage Pressure at Completion of Pre-Pressurization 31.1 psia

Drain Operation

Time	Pressurant Temperature °K	Pressurant Temperature °F	Ullage Pressure psia
T + 0	198.6	-102.0	31.7
T + 10	154.0	-182.3	30.1
T + 20	140.5	-206.6	30.2
T + 45	117.1	-248.7	31.0
T + 70	113.7	-254.8	31.1
T + 95	114.8	-252.9	30.6
T + 145	110.7	-260.2	30.6
T + 195	113.7	-254.8	30.3
T + 245	113.1	-256.0	30.7
T + 295	113.1	-256.0	30.6
T + 345	110.1	-261.3	30.7
T + 395	110.7	-260.3	30.5
T + 406	108.4	-264.4	30.7
T + 407.7	110.1	-261.3	30.6

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
43 to 42	1.8	25.5	850
42 to 34	12.6	219.7	1042
34 to 22	20.0	339.9	1020
22 to 10	19.3	348.2	1015
10 to 9	40.8	696.5	1022
9 to 8	40.5	656.5	972
8 to 6	81.4	1392.9	1025
6 to 4	80.8	1393.0	1033
4 to 3	40.8	696.4	1008
3 to 2	38.3	695.4	1082
2 to 1	24.1	395.2	979
1 to Empty	6.0	74.5	745

Sensors No. 5 and 7 did not respond properly.

Sensor Response During Pre-Pressurization

Sensor No.	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	4.5
44	30.5
43	1.3 (after start of drain)

Vacuum Bell Pressure

Start of Pre-Pressurization	340 microns
Start of Drain	475 microns
Middle of Drain	275 microns

After 5 Minute Stabilization

Ullage Pressure	30.7 psia	
Temperature at Diffuser	98.8°K	-281.6°F
Temperature at 150" Level	98.8°K	-281.6°F
Temperature at 30.81" Level	41.6°K	-384.6°F
Temperature in Outflow Line	48.9°K	-371.5°F

Channels Out During Run

13
16
30
48

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BEECH AIRCRAFT CORPORATION

DOCUMENT NUMBER	REVISION	PAGE NO.
FR 13632	A	51.0
ISSUE DATE: 11-25-64	REVISION DATES: "A" 5/5/65	

Run Number 6

Date Test Conducted: 21 August 1964

Pre-Pressurant Gas	0°F Helium
Pressurant Gas	0°F Helium
Barometric Pressure	621.20
Operating Pressure	30 psia
Pre-Pressurization time	49.8 seconds
Stabilization Time	11.0 seconds
Drain Time	402.5 seconds
Ullage (Prior to Pre-Press.)	5% (App. 6998.9 Gallons)

Pre-Pressurant Gas Temperature

Time	Temperature °K	Temperature °F
T + 0	279.2	43.1
T + 10	279.5	43.6
T + 20	279.8	44.1
T + 30	280.4	45.1
T + 40	279.8	44.1
T + 49.8	280.4	45.1

Ullage Pressure at Completion of Pre-Pressurization 31.4 psia

Drain Operation

Time	Pressurant Temperature °K	Pressurant Temperature °F	Ullage Pressure psia
T + 0	214.6	-74.8	30.9
T + 1	221.5	-60.8	32.5
T + 3	236.8	-34.7	33.4
T + 5	216.3	-70.7	30.2
T + 6	226.9	-51.0	30.7
T + 26	260.4	9.2	31.4
T + 46	267.1	21.2	31.3
T + 71	270.0	26.5	31.3
T + 96	272.5	31.1	31.1
T + 146	274.3	34.2	31.1
T + 196	276.2	37.6	31.2
T + 246	278.0	40.9	31.2
T + 296	278.9	42.5	30.7
T + 346	280.1	44.6	31.2
T + 396	281.7	44.6	31.2
T + 401	280.4	45.3	30.6
T + 402.5	280.7	45.7	30.5

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BEECH AIRCRAFT CORPORATION ENGINEERING TEST LABORATORIES

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Run Number 6, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	19.7	339.9	1058
22 to 10	19.6	348.2	1085
10 to 9	40.7	696.5	1030
9 to 8	40.5	656.5	985
8 to 6	80.7	1392.9	1038
6 to 4	79.8	1393.0	1050
4 to 3	40.6	696.4	1039
3 to 2	33.5	695.4	1090
2 to 1	23.9	395.2	1000
1 to Empty	5.7	74.5	782

Sensors No. 5 and 7 did not respond properly.

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
44	3.4
43	6.7
42	30.6
34	12.8 (after start of drain)
46	0.8 (Prior to start of Pre-Press.)

Vacuum Bell Pressure

Start of Drain	1100 microns
T + 200	500 microns

After 5 Minute Stabilization

Ullage Pressure	30.9 psia	
Temperature at Diffuser	232.9°K	-40.3°F
Temperature at 150" Level	184.7°K	-127.0°F
Temperature at 30.81" Level	48.2°K	-372.7°F
Temperature in Outflow Line	55.2°K	-360.1°F

BEECH TEST REPORT

Run Number 7

Date Test Conducted: 22 August 1964

Pre-Pressurant Gas	-300°F Helium
Pressurant Gas	-300°F Helium
Barometric Pressure	619.40
Operating Pressure	30 psia
Pre-Pressurization Time	45.6 seconds
Stabilization Time	20.5 seconds
Drain Time	406.5 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	260.4	9.2
T + 10	259.7	8.0
T + 20	257.1	3.3
T ± 30	255.8	0.9
T + 40	253.8	-2.6
T + 45.6	254.1	-2.1

Ullage Pressure at End of Pre-Pressurization 31.4 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	180.9	-133.9	30.4
T + 2	196.3	-106.1	31.0
T + 12	215.7	-71.3	30.1
T + 22	225.5	-53.6	29.9
T + 42	217.1	-68.6	29.5
T + 62	215.3	-72.0	29.8
T + 87	210.5	-80.6	30.0
T + 112	206.3	-88.2	30.4
T + 137	202.9	-94.3	30.5
T + 187	199.0	-101.4	30.7
T + 237	195.9	-106.9	30.9
T + 287	191.9	-114.1	31.0
T + 337	191.9	-114.1	31.0
T + 387	189.9	-117.7	31.0
T + 397	190.3	-117.0	31.0
T + 405	190.7	-116.2	31.1
T + 406.5	189.5	-118.4	30.7

Run Number 7, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	19.9	339.9	1027
22 to 10	19.6	343.2	1065
10 to 9	40.7	696.5	1025
9 to 8	41.2	656.5	953
8 to 6	81.4	1392.9	1023
6 to 4	81.1	1393.0	1031
4 to 3	41.0	696.4	1018
3 to 2	38.8	695.4	1102
2 to 1	24.3	395.2	971
1 to Empty	5.4	74.5	839

Sensors 5 and 7 did not Respond Properly

Sensor Response During Pre-Pressurization

Sensor	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
43	1.7
42	20.2
34	13.1 (After Start of Drain)

Vacuum Bell Pressure

During Drain	
T + 132	350 microns
T + 150	300 microns
T + 200	250 microns
T + 250	225 microns
T + 322	300 microns
T + 400	400 microns

After 5 Minute Stabilization

Ullage Pressure	30.5 psia	
Temperature at Diffuser	173.0°K	-147.0°F
Temperature at 150" Level	153.7°K	-182.8°F
Temperature at 30.31" Level	40.4°K	-386.8°F
Temperature in Outflow Line	45.0°K	-378.5°F

BEECH TEST REPORT

BEECH AIRCRAFT CORPORATION

TEST NUMBER	REVISION	PAGE NO.
FR 13632	A	55.0
11-25-64	"A" 5/5/65	

Run Number 8

Date Test Conducted: 27 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	100°F Hydrogen
Barometric Pressure	617.45
Operating Pressure	50 psia
Pre-Pressurization Time	48.7 seconds
Stabilization Time	7.4 seconds
Drain Time	36.8 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	Temperature °F
T + 0	263.0	13.9
T + 10	243.4	-21.4
T + 20	229.1	-47.2
T + 30	211.6	-78.6
T + 40	191.5	-114.8
T + 48.7	177.1	-139.6

Ullage Pressure at Completion of Pre-Pressurization 49.4 psia

Drain Operation

Time	Pressurant Temperature °K	Pressurant Temperature °F	Ullage Pressure psia
T + 0	245.4	-17.9	47.8
T + 2	222.6	-58.9	50.4
T + 4	218.2	-66.7	48.1
T + 6	208.6	-84.0	50.2
T + 8	206.7	-87.4	48.3
T + 10	201.0	-97.7	49.7
T + 12	201.4	-96.9	48.3
T + 14	196.3	-106.1	49.7
T + 16	195.1	-108.3	49.1
T + 18	192.7	-112.7	49.1
T + 20	190.7	-116.2	49.0
T + 22	186.7	-123.7	49.7
T + 24	188.7	-119.9	48.5
T + 26	182.5	-130.9	50.4
T + 30	182.5	-130.9	49.7
T + 32	181.3	-133.2	49.4
T + 34	180.9	-133.9	48.3
T + 35	179.6	-136.9	49.3
T + 36	178.8	-137.7	50.2
T + 36.8	175.4	-143.8	50.3
T + 37.3	176.2	-142.4	50.1
Tank Rupture	333.6	NG	13.2

Run Number 8, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	19.8	339.9	1030
22 to Rupture	7.0		

Sensor 44 out of Liquid 2.9 seconds after start of Pre-Pressurization
Sensor 43 out of Liquid 4.2 seconds after start of Pre-Pressurization
Sensor 42 out of Liquid 22.2 seconds after start of Pre-Pressurization
Sensor 34 out of Liquid 13.2 seconds after start of Drain
Sensor 22 out of Liquid 6.0 seconds prior to Rupture
Sensor 46 out of Liquid 1.2 seconds Prior to start of Pre-Pressurization

Vacuum Bell Pressure

Start of Pre-Pressurization	100 microns
End of Pre-Pressurization	2800 microns
Start of Drain	2800 microns

Channels Disconnected from Commutator

13
16
41
43
48
59

Run Number 11

Date Test Conducted: 22 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	100°F Hydrogen
Barometric Pressure	620.20
Operating Pressure	20 psia
Pre-Pressurization Time	52.8 seconds
Stabilization Time	13.0 seconds
Drain Time	421.6 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	274.9	35.5
T + 10	270.0	26.5
T + 20	275.9	37.1
T + 30	281.0	46.3
T + 40	285.5	54.4
T + 50	291.1	64.5
T + 52.8	291.7	65.6

Ullage Pressure at Completion of Pre-Pressurization 20.2 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	174.5	-145.4	19.7
T + 3	206.3	-88.3	19.9
T + 13	235.1	-36.3	19.2
T + 23	245.4	-17.9	19.2
T + 43	260.1	8.7	19.4
T + 63	272.8	31.7	19.7
T + 93	281.0	46.2	19.8
T + 143	286.7	56.5	19.7
T + 193	288.3	60.3	19.8
T + 243	283.5	50.8	19.4
T + 295	279.5	43.6	19.5
T + 343	274.0	33.7	20.0
T + 393	266.8	20.7	19.8
T + 418	266.2	19.7	19.4
T + 421.6	263.9	15.5	19.7

Run Number 11, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
42 to 34	14.1	219.7	912
34 to 22	20.2	339.9	963
22 to 10	19.6	343.2	1063
10 to 9	41.2	696.5	1016
9 to 8	40.5	656.5	902
8 to 6	81.9	1392.9	1012
6 to 4	83.5	1393.0	1000
4 to 3	42.9	696.4	976
3 to 2	41.5	695.4	1008
2 to 1	26.7	395.2	890
1 to Empty	6.8	74.5	664

Sensors 5 and 7 did not Respond Properly

Sensor Response During Pre-Pressurization

Sensor Number	Sensor out of Liquid Seconds After Start of Pre-Pressurization)
44	At Start
43	6.8
42	2.7 (After Start of Drain)

Vacuum Bell Pressure

Start of Drain	250 microns
Middle of Drain	300 microns

After 5 Minute Stabilization

Ullage Pressure	19.4 psia	
Temperature at Diffuser	230.3°K	-44.9°F
Temperature at 150" Level	173.4°K	-147.4°F
Temperature at 30.81" Level	41.3°K	-385.2°F
Temperature in Outflow Line	51.9°K	-366.0°F

Run Number 12

Date Test Conducted: 22 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-100°F Hydrogen
Barometric Pressure	620.00
Operating Pressure	20 psia
Pre-Pressurizing Time	59.5 seconds
Stabilization Time	8.9 seconds
Drain Time	408.1 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	280.4	45.2
T + 10	244.1	-20.0
T + 20	204.5	-91.4
T + 30	178.4	-138.4
T + 40	178.4	-138.4
T + 50	183.8	-128.6
T + 59.5	185.0	-126.0

Ullage Pressure at Completion of Pre-Pressurization 20.8 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	185.0	-126.0	20.4
T + 5	196.3	-106.1	20.0
T + 15	201.4	-97.0	20.4
T + 40	201.0	-97.7	19.9
T + 65	201.8	-96.2	20.0
T + 115	202.9	-94.3	20.4
T + 165	204.5	-91.4	20.7
T + 215	204.8	-90.9	20.7
T + 265	204.8	-90.9	20.6
T + 315	205.6	-89.4	20.6
T + 365	206.0	-88.7	20.5
T + 408.1	202.6	-94.8	20.4

Run Number 12, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
42 to 34	13.2	219.7	1000
34 to 22	19.3	339.9	1055
22 to 10	19.7	348.2	1052
10 to 9	41.0	696.5	1018
9 to 8	40.7	656.5	985
8 to 6	81.3	1392.9	1028
6 to 4	81.1	1393.0	1032
4 to 3	40.8	696.4	1024
3 to 2	39.0	695.4	1070
2 to 1	24.7	395.2	914
1 to Empty	6.3	74.5	704

Sensors 5 and 7 did not Respond Properly

Sensors Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
43	1.4
42	1.0 (After Start of Drain)

Vacuum Bell Pressure

Pre-Pressurization		200 microns
Drain	T + 0	725 microns
	T + 115	600 microns
	T + 150	450 microns
	T + 200	400 microns
	T + 250	300 microns
	T + 280	275 microns
	T + 300	250 microns
	T + 330	225 microns
	T + 408.1	225 microns

After 5 Minute Stabilization

Ullage Pressure	20.4 psia	
Temperature at Diffuser	179.7°K	-136.0°F
Temperature at 150" Level	155.2°K	-130.1°F
Temperature at 30.81" Level	40.1°K	-387.3°F
Temperature in Outflow Line	49.4°K	-370.6°F

Run Number 13

Date Test Conducted: 22 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-300°F Hydrogen
Barometric Pressure	619.7
Operating Pressure	20 psia
Pre-Pressurization Time	73.5 seconds
Stabilization Time	9.0 seconds
Drain Time	415.4 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	256.4	2.0
T + 10	196.2	-106.3
T + 20	149.2	-190.9
T + 30	115.3	-252.0
T + 40	80.1	-315.4
T + 50	82.3	-311.4
T + 60	94.0	-290.3
T + 70	86.7	-303.4
T + 73.5	89.5	-298.4

Ullage Pressure at Completion of Pre-Pressurization 20.7 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	175.8	-143.0	20.6
T + 3	167.1	-158.7	20.7
T + 28	139.5	-208.4	21.0
T + 53	129.2	-226.9	20.3
T + 103	117.7	-247.6	20.7
T + 153	117.1	-248.7	20.3
T + 203	114.8	-252.9	20.8
T + 253	118.2	-246.7	20.1
T + 303	117.1	-248.7	20.1
T + 353	112.5	-257.0	20.6
T + 403	117.1	-248.7	20.4
T + 413	116.5	-249.8	20.6
T + 415.4	117.1	-248.7	20.3

Run Number 13, Continued...

Sensor Number	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
43 to 42	2.0	25.5	765
42 to 34	12.9	219.7	1022
34 to 22	19.8	339.9	1030
22 to 10	19.7	348.2	1052
10 to 9	41.3	696.5	1010
9 to 8	40.7	656.5	966
8 to 6	81.5	1392.9	1025
6 to 4	82.3	1393.0	1016
4 to 3	41.6	696.4	1002
3 to 2	40.2	695.4	1030
2 to 1	25.5	395.2	927
1 to Empty	6.3	74.5	715

Sensors 5 and 7 did not Respond Properly

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
44	0.8
43	1.6 (After Start of Drain)
46	8.5 (Before Start of Pre-Press.)

Vacuum Bell Pressure

Pre-Pressurization		225 microns
Drain	T + 0	250 microns
	T + 50	550 microns
	T + 100	425 microns
	T + 160	325 microns
	T + 270	250 microns
	T + 320	225 microns
	T + 345	200 microns
	T + 415.4	200 microns

After 5 Minute Stabilization

Ullage Pressure	20.8 psia	
Temperature at Diffuser	104.2°K	-272.1°F
Temperature at 150" Level	104.2°K	-272.1°F
Temperature at 30.81" Level	40.4°K	-386.8°F
Temperature in Outflow Line	46.6°K	-375.6°F

Run Number 14

Date Test Conducted: 21 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-100°F Hydrogen
Barometric Pressure	621.20
Operating Pressure	30 psia
Pre-Pressurization Time	46.4 seconds
Stabilization Time	6.9 seconds
Drain Time	757.7 seconds
Ullage (Prior to Pre-Press.)	5%

Pre-Pressurant Gas Temperature

Time	Temperature °K	Temperature °F
T + 0	221.5	-60.8
T + 10	173.7	-146.8
T + 20	174.1	-146.1
T + 30	183.8	-128.7
T + 40	136.7	-123.4
T + 46.4	193.5	-111.2

Ullage Pressure at Completion of Pre-Pressurization 31.9 psia

Drain Operation

Time	Pressurant Temperature °K	Pressurant Temperature °F	Ullage Pressure psia
T + 0	226.2	-52.3	32.2
T + 3	219.0	-65.3	31.3
T + 13	213.1	-76.0	32.0
T + 31	210.5	-80.6	31.6
T + 81	207.1	-86.7	32.2
T + 131	205.6	-89.4	31.6
T + 181	205.2	-90.1	31.8
T + 231	205.2	-90.1	32.2
T + 281	204.1	-92.2	31.8
T + 331	204.8	-90.9	32.0
T + 381	204.8	-90.9	31.6
T + 431	206.0	-88.7	31.6
T + 481	206.3	-88.3	31.7
T + 531	205.6	-89.4	31.4
T + 581	205.6	-89.4	32.0
T + 631	205.6	-89.4	31.8
T + 681	206.0	-88.7	31.9
T + 731	206.7	-87.5	31.8
T + 757.7	204.8	-90.9	31.6

Run Number 14, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
42 to 34	24.6	219.7	539
34 to 22	37.8	339.9	541
22 to 10	37.1	348.2	563
10 to 9	77.7	696.5	540
9 to 8	75.1	656.5	525
8 to 6	150.8	1392.9	530
6 to 5	75.1	696.5	537
5 to 4	75.9	696.5	553
4 to 3	76.5	696.4	547
3 to 2	72.0	695.4	579
2 to 1	44.3	395.2	537
1 to Empty	10.2	74.5	443

Sensor No. 7 did not indicate

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	4.2
44	5.6
43	7.3
42	0.6 (After Start of Drain)

After 5 Minute Stabilization

Ullage Pressure	31.0 psia	
Temperature at the Diffuser	190.0°K	-117.5°F
Temperature at the 150" Level	178.2°K	-138.7°F
Temperature at the 30.81" Level	41.6°K	-384.6°F
Temperature in the Outflow Line	48.2°K	-372.4°F

Run Number 16

Date Test Conducted: 26 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-300°F Hydrogen
Barometric Pressure	618.00
Operating Pressure	30 psia
External Heat Flux	450 BTU/Ft^2/Hr
Pre-Pressurization Time	53.8 seconds
Stabilization Time	10.0 seconds
Drain Time	403.6 seconds
Ullage (Prior to Pre-Press.)	5%
Limiter (Voltage)	10%
Heat Setting (Heat Rate Computer)	80%
Skin Temperature	-300°F

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	237.2	-32.5
T + 10	179.9	-139.3
T + 20	129.7	-226.2
T + 30	92.1	-293.7
T + 40	69.3	-334.7
T + 50	69.3	-334.7
T + 53.8	73.2	-327.9

Ullage Pressure at Completion of Pre-Pressurization 31.2 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	222.2	-59.5	30.1
T + 5	172.4	-149.2	30.2
T + 25	133.4	-219.3	30.2
T + 45	117.7	-247.8	31.3
T + 75	111.9	-258.1	30.5
T + 95	110.7	-260.3	30.9
T + 100	109.0	-263.3	31.0
T + 150	107.2	-266.6	31.4
T + 200	111.9	-258.1	30.7
T + 250	109.6	-262.3	31.2
T + 300	110.7	-260.3	30.9
T + 350	108.4	-264.5	31.1
T + 400	111.9	-258.1	30.7
T + 403.6	108.4	-264.5	30.9

Run Number 16, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	19.6	339.9	1032
22 to 10	20.0	348.2	1043
10 to 9	40.1	696.5	1037
9 to 8	40.1	656.5	980
8 to 6	80.7	1392.9	1032
6 to 4	80.3	1393.0	1040
4 to 3	40.5	696.4	1038
3 to 2	38.5	695.4	1075
2 to 1	25.0	395.2	945
1 to Empty	6.0	74.5	750

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	1.2
44	5.7
43	5.7
42	11.2
34	12.8 (After Start of Drain)

Sensors 5 and 7 did not Respond Properly

Channels Disconnected

10	48
13	59
16	41
43	

Vacuum Bell Data

Start of Pre-Pressurization		90 microns
End of Pre-Pressurization		1750 microns
Drain	T + 60	2250 microns
	T + 200	1400 microns
	T + 300	1200 microns
	T + 400	1400 microns
After 5 Minute Stabilization		100 microns

After 5 Minute Stabilization

Ullage Pressure	32.9 psia	
Temperature at Diffuser	-247.7°F	117.7°K
Temperature at 150" Level	-248.1°F	117.5°K
Temperature at 30.81" Level	-367.3°F	51.2°K
Temperature in Outflow Line	29.4°F	271.6°K

Run Number 17

Date Test Conducted: 25 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-200°F Hydrogen
Barometric Pressure	618.00
Operating Pressure	30 psia
External Heat Flux	450 BTU/Ft^2/Hr
Pre-Pressurization Time	50.1 seconds
Stabilization Time	7.1 seconds
Drain Time	401.8 seconds
Ullage (Prior to Pre-Press.)	5%
Limiter (Voltage)	10%
Heat Setting (Heat Rate Computer)	80%
Skin Temperature	-300°F

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	181.7	-132.6
T + 10	153.5	-183.2
T + 20	125.4	-234.0
T + 30	119.9	-243.8
T + 40	125.4	-234.0
T + 50.1	134.9	-216.8

Ullage Pressure at Completion of Pre-Pressurization 31.0 psia

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	235.4	-36.0	30.8
T + 3	216.0	-70.9	30.0
T + 10	189.5	-118.5	30.5
T + 40	161.3	-169.3	30.3
T + 70	151.6	-186.8	30.6
T + 120	147.8	-193.6	30.5
T + 170	148.3	-192.7	30.6
T + 220	147.3	-194.5	30.6
T + 270	147.3	-194.5	31.4
T + 320	147.3	-194.5	31.1
T + 370	146.4	-196.1	31.0
T + 400	146.9	-195.2	30.9
T + 401.8	146.9	-195.2	30.3

Run Number 17, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	19.8	339.9	1030
22 to 10	19.4	348.2	1075
10 to 9	40.4	696.5	1030
9 to 8	40.1	646.5	985
8 to 6	80.2	1392.9	1045
6 to 4	79.7	1393.0	1063
4 to 3	40.3	696.4	1035
3 to 2	38.2	695.4	1087
2 to 1	24.1	395.2	980
1 to Empty	6.4	74.5	700

Sensors 5 and 7 did not Play Properly

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	1.8
44	4.1
43	7.3
42	31.4
34	13.2 (After Start of Drain)

Channels Disconnected

13	43
16	48
41	

Vacuum Bell Pressure

Start of Pre-Pressurization		70 microns
End of Pre-Pressurization		2000 microns
Stabilization		2000 microns
Drain	T + 60	2500 microns
	T + 200	1500 microns
	T + 300	1250 microns
	T + 400	1300 microns
After 5 Minute Stabilization		1500 microns

After 5 Minute Stabilization

Ullage Pressure	32.4 psia	
Temperature at Diffuser	153.1 °K	-174.9°F
Temperature at 150" Level	158.3 °K	-174.5°F
Temperature at 30.81" Level	55.2 °K	-360.2°F
Temperature at Outflow Line	271.9 °K	29.8°F

Run Number 18

Date Test Conducted: 25 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-100°F Hydrogen
Barometric Pressure	621.25
Operating Pressure	30 psia
External Heat Flux	450 $BTU/Ft^2/Hr$
Voltage Limiter	10%
Heat Rate Computer Time	80%
Skin Temperature	-300°F
Ullage (Prior to Pre-Press.)	5%
Pre-Pressurization Time	46.6 seconds
Stabilization Time	6.5 seconds
Drain Time	427.4 seconds

Pre-Pressurant Gas Temperature

Time	Temperature °K	Temperature °F
T + 0	297.7	76.3
T + 10	277.4	39.8
T + 20	243.7	-21.0
T + 30	204.5	-91.5
T + 40	179.2	-137.1
T + 46.6	174.5	-145.6

Ullage Pressure at Completion of Pre-Pressurization 31.5 psia

Drain Operation

Time	Pressurant Temperature °K	Pressurant Temperature °F	Ullage Pressure psia
T + 0	229.1	-47.2	30.7
T + 5	219.7	-64.2	29.9
T + 10	210.5	-80.7	31.2
T + 50	198.2	-102.9	30.4
T + 100	198.2	-102.9	30.8
T + 150	197.8	-103.6	30.6
T + 200	197.8	-103.6	31.0
T + 250	198.2	-102.9	30.7
T + 300	197.8	-103.6	30.7
T + 350	199.0	-101.4	30.7
T + 400	196.3	-106.3	31.3
T + 427.4	191.5	-115.0	30.9

Run Number 18, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	20.1	339.9	1030
22 to 10	21.6	348.2	982
10 to 9	44.5	696.5	942
9 to 8	43.8	656.5	905
8 to 6	87.3	1392.9	960
6 to 4	87.8	1393.0	961
4 to 3	41.6	696.4	1010
3 to 2	41.9	695.4	1000
2 to 1	26.8	395.2	806
1 to Empty	6.4	74.5	722

Heating applied approximately five (5) minutes prior to pre-pressurization.
All sensors except 48 covered at the start of heating.
Sensor 34 uncovered 5.6 seconds after start of drain.
Sensors 5 and 7 did not respond properly.

Channels Disconnected

13	43
16	48
41	

Vacuum Bell Pressure

Start of Pre-Pressurization		70 microns
End of Pre-Pressurization		1250 microns
Stabilization		2000 microns
Drain	T + 0	2250 microns
	T + 60	1750 microns
	T + 200	1500 microns
	T + 300	1200 microns
	T + 400	1050 microns
After 5 Minute Stabilization		1300 microns

After 5 Minute Stabilization

Ullage Pressure	31.4 psia	
Temperature at Diffuser	196.5°K	-106.0°F
Temperature at 150" Level	188.0°K	-121.1°F
Temperature at 30.81" Level	36.9°K	-393.0°F
Temperature in Outflow Line	20.4°K	-422.6°F

Run Number 22

Date Test Conducted: 26 August 1964

Pre-Pressurant Gas	0°F Hydrogen
Pressurant Gas	-100°F Hydrogen
Barometric Pressure	617.45
Operating Pressure	30 psia
External Heat Flux	900 BTU/Ft^2/Hr
Limiter (Voltage)	13%
Heat Setting (Heat Rate Computer)	90%
Skin Temperature	-150°F
Ullage (Prior to Pre-Press.)	5%
Pre-Pressurization Time	70.8 seconds
Stabilization Time	7.0 seconds
Drain Time	402.0 seconds

Pre-Pressurant Gas Temperature

Time	Temperature °K	°F
T + 0	268.1	22.9
T + 10	234.0	-38.5
T + 20	201.0	-97.8
T + 30	174.1	-146.2
T + 40	175.0	-144.6
T + 50	183.0	-130.2
T + 60	185.4	-126.0
T + 70	191.9	-114.2
T + 70.8	188.7	-120.0

Ullage Pressure at Completion of Pre-Pressurization 31.0

Drain Operation

Time	Pressurant Temperature °K	°F	Ullage Pressure psia
T + 0	234.0	-38.4	30.7
T + 5	221.9	-60.2	29.8
T + 10	216.8	-69.4	30.0
T + 50	203.7	-93.0	31.1
T + 100	204.1	-92.3	30.7
T + 150	202.2	-95.7	30.6
T + 200	204.5	-91.6	30.9
T + 250	205.6	-89.6	30.7
T + 300	204.5	-91.6	31.0
T + 350	206.0	-88.9	30.7
T + 400	205.6	-89.6	31.1
T + 402.0	203.3	-93.7	30.9

Run Number 22, Continued...

Sensor Response During Drain

Sensors	Time (Sec.)	Volume (Gal.)	Flow Rate (GPM)
34 to 22	21.4	339.9	954
22 to 10	19.0	348.2	1100
10 to 9	40.2	696.5	1035
9 to 8	42.4	656.5	926
8 to 6	80.1	1392.9	1042
6 to 4	80.0	1393.0	1042
4 to 3	41.3	696.4	997
3 to 2	40.2	695.4	1035
2 to 1	25.0	395.2	812
1 to Empty	5.4	74.5	812

Sensors 5 and 7 did not Respond Properly

Sensor Response During Pre-Pressurization

Sensor Number	Sensor Out of Liquid (Seconds After Start of Pre-Pressurization)
46	4
44	4
43	4.2
42	6.1
34	6.5 (After Start of Drain)

Channels Disconnected

13	41
16	43
19	48

Vacuum Bell Pressure

Start of Pre-Pressurization		60 microns
End of Pre-Pressurization		1250 microns
Stabilization		1250 microns
Drain	T + 60	1400 microns
	T + 200	1300 microns
	T + 300	1000 microns
	T + 400	1750 microns
After 5 Minute Stabilization		1400 microns

After 5 Minute Stabilization

Ullage Pressure	33.0 psia	
Temperature at Diffuser	194.8°K	-108.8°F
Temperature at 150" Level	127.7°K	-229.6°F
Temperature at 30.81" Level	35.3°K	-396.1°F
Temperature in Outflow Line	272.3°K	30.6°F

APPENDIX A

NASA PRESSURIZATION STUDY RUN SEQUENCE

Page 74.0

BEECH TEST REPORT

Beech Aircraft Corporation — Environmental Test Laboratories

Document No.	Rev	Page
FR 13632	A	74.0
Issue Date 11-25-64	Revision Dates "A" 5/5/65	

NASA PRESSURIZATION STUDY RUN SEQUENCE

RUN NO.	COMP. DATE	BAROMETRIC PRESSURE	OPERATING PRESSURE (PSIA)	PRE-PRESSURANT GAS AND TEMP. (°F)	PRESSURANT GAS + TEMP. (°F)	DRAIN TIME (SEC)	EXT HEAT FLUX BTU/FT^2/HOUR
1	July 31	N/A	30	0° Hydrogen	100° Hydrogen	400	0
3	Aug. 20	617.50	30	0° Hydrogen	-100° Hydrogen	400	0
4	Aug. 21	621.70	30	0° Hydrogen	-200° Hydrogen	400	0
2	Aug. 21	621.70	30	0° Helium	0° Hydrogen	400	0
14	Aug. 21	621.20	30	0° Hydrogen	-100° Hydrogen	800	0
6	Aug. 21	621.20	30	0° Helium	0° Helium	400	0
7	Aug. 22	619.40	30	-300° Helium	-300° Helium	400	0
5	Aug. 22	620.50	30	-300° Helium	-300° Hydrogen	400	0
11	Aug. 22	620.20	20	0° Hydrogen	100° Hydrogen	400	0
12	Aug. 22	620.00	20	0° Hydrogen	-100° Hydrogen	400	0
13	Aug. 22	619.70	20	0° Hydrogen	-300° Hydrogen	400	0
18	Aug. 25	621.25	30	0° Hydrogen	-100° Hydrogen	400	450
17	Aug. 26	618.00	30	0° Hydrogen	-200° Hydrogen	400	450
16	Aug. 26	618.00	30	0° Hydrogen	-300° Hydrogen	400	450
22	Aug. 26	617.45	30	0° Hydrogen	-100° Hydrogen	400	900
8	Aug. 27	617.15	50	0° Hydrogen	100° Hydrogen	400	0

APPENDIX B

PROPELLANT AND PRESSURIZATION SCHEMATIC

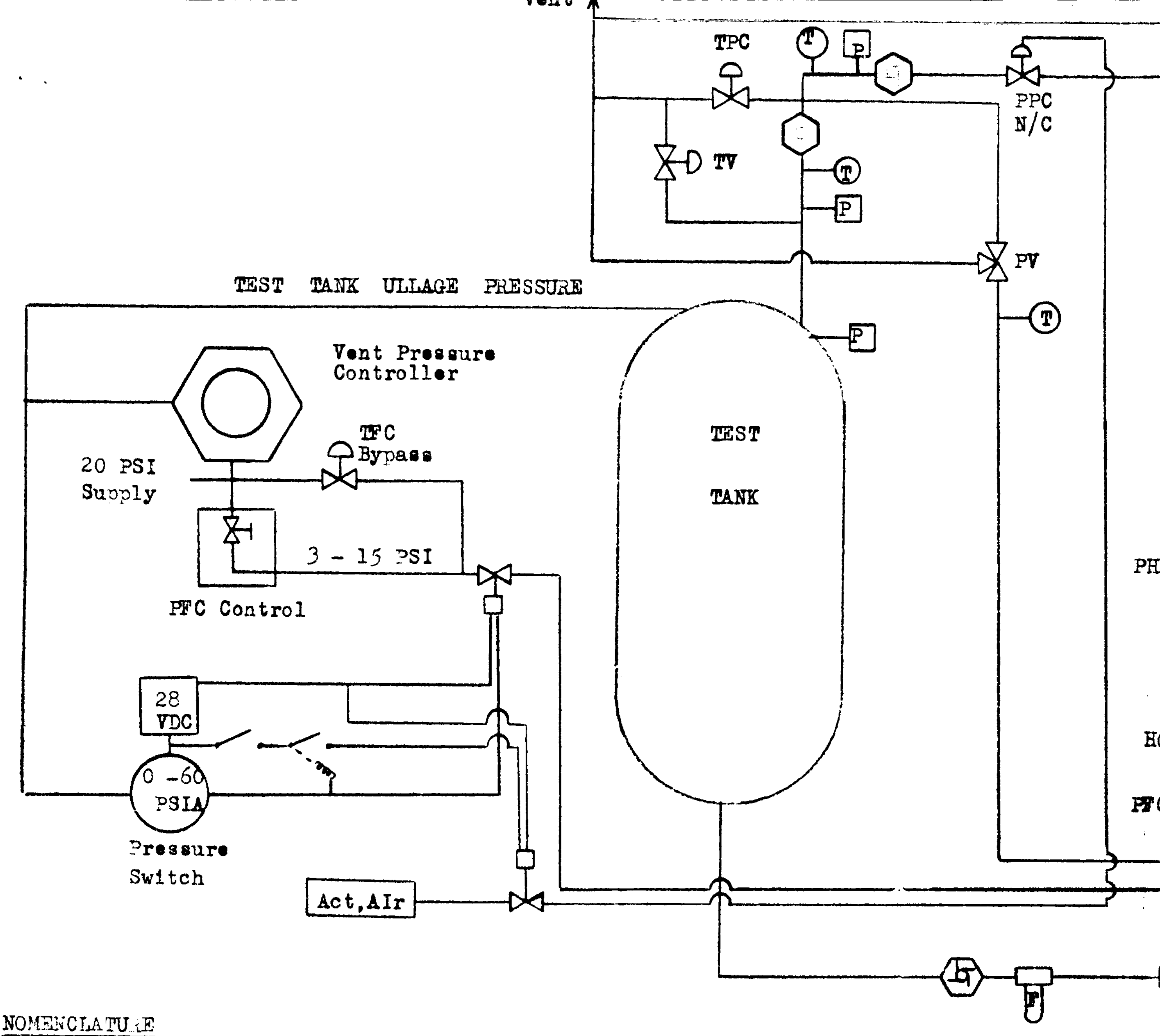
THERMAL TEST FACILITY

Page 76.0

APPENDIX C

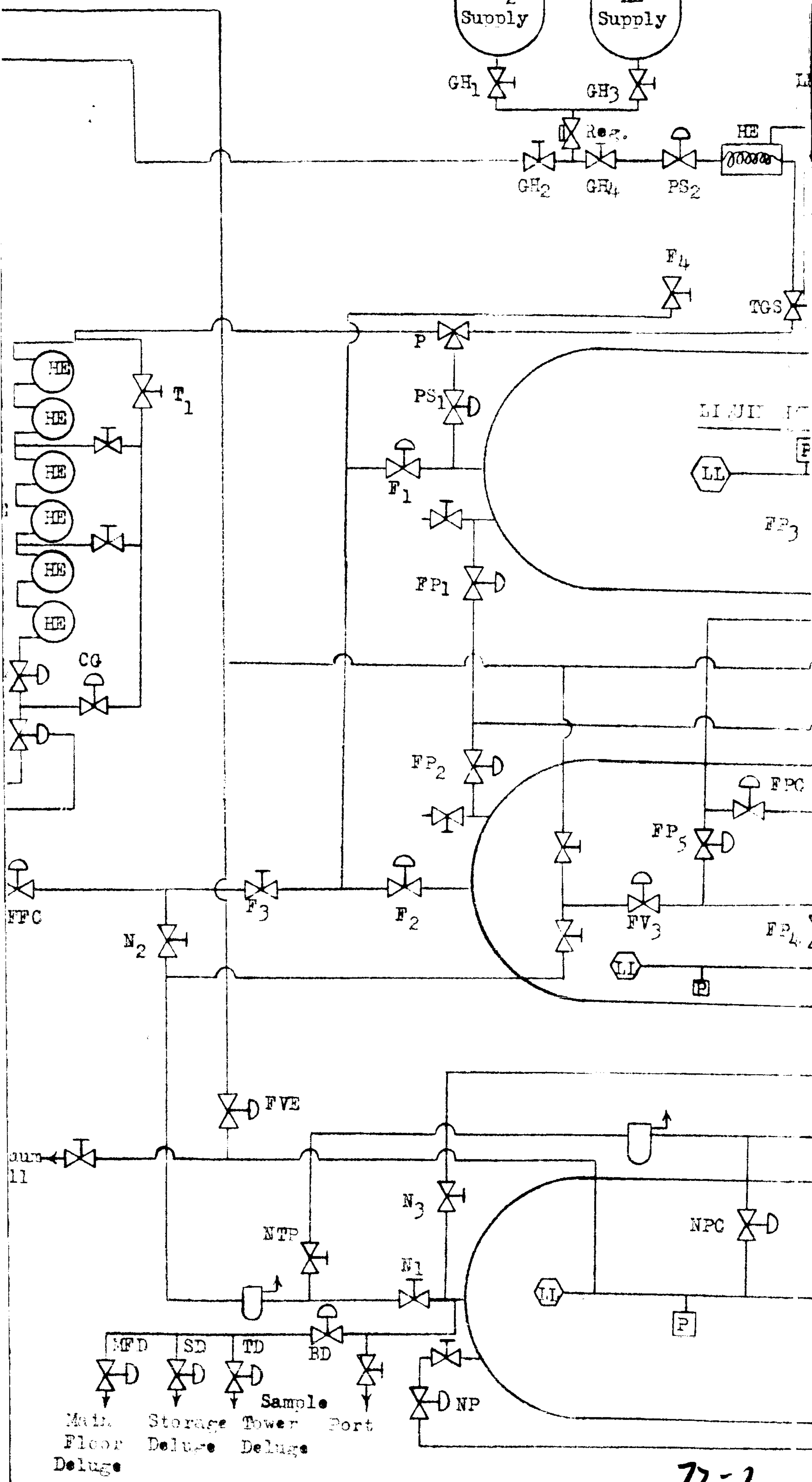
PRESSURIZATION CONTROL SYSTEM SCHEMATIC

Page 78.0



NOMENCLATURE

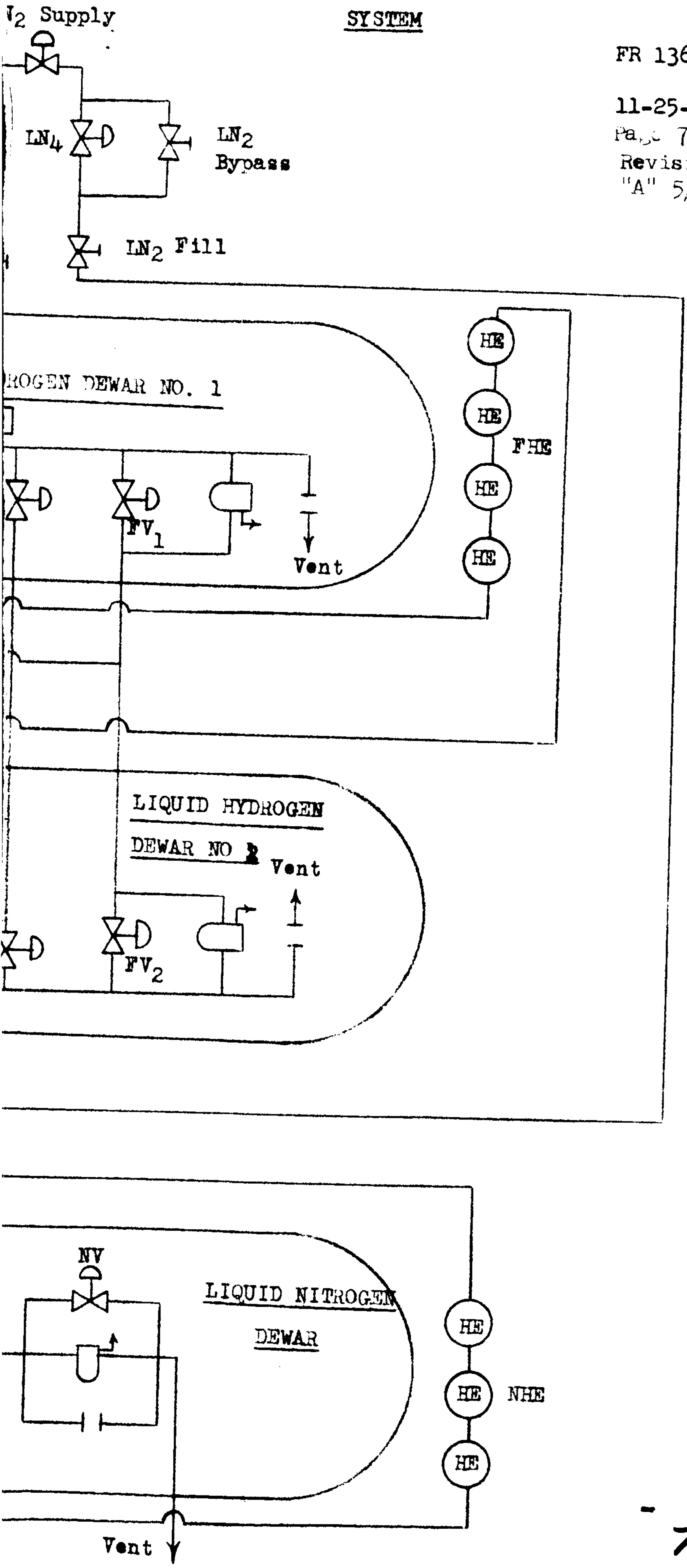
- Pneumatically Controlled Valve
- Hand Operated Valve
- Flow Meter
- Filter
- Pressure Relief Valve
- Burst Disc
- Pressure Regulator
- Heat Exchanger
- Pressure Transducer
- Temperature Probe
- Three Way Valve
- Liquid Level Indicator
- Solenoid Valve
- LN_2 Heat Exchanger

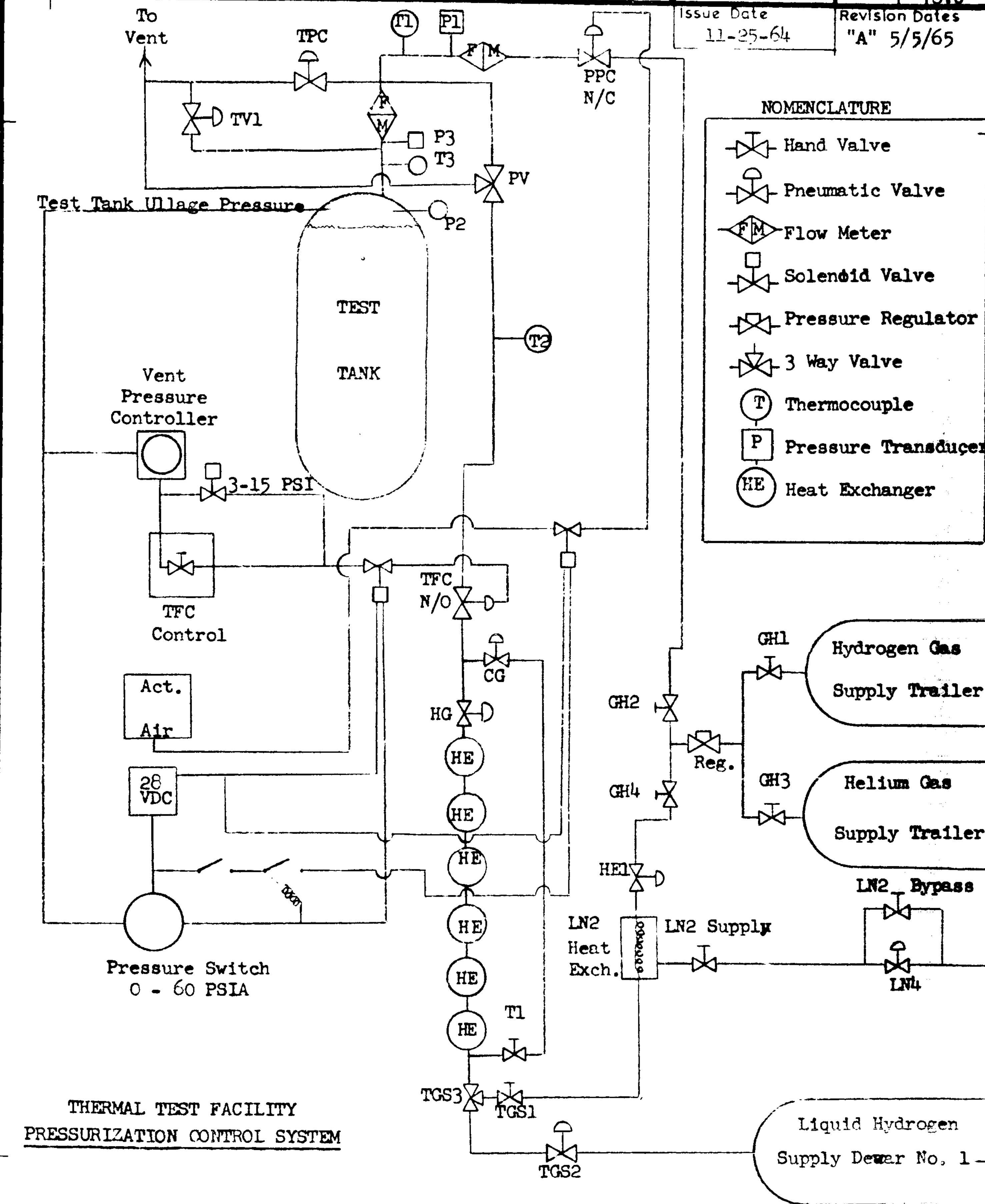


Supply
Supply
GH1
GH3
Reg.
HE
GH2
GH4
PS2
F4
TGS
P
HE
HE
HE
HE
HE
HE
T1
PS1
F1
LL
FP3
FP1
CG
FP2
FPC
FP5
FFC
F3
F2
FV3
FP4
N2
LI
P
FVE
N3
NPC
NTP
N1
LI
P
MFD
SD
TD
BD
NP
Sample
Main Floor Deluge
Storage Deluge
Tower Deluge
Port

77-2

HEAT TOWER, PROPELLANT AND PRESSURIZATION SYSTEM





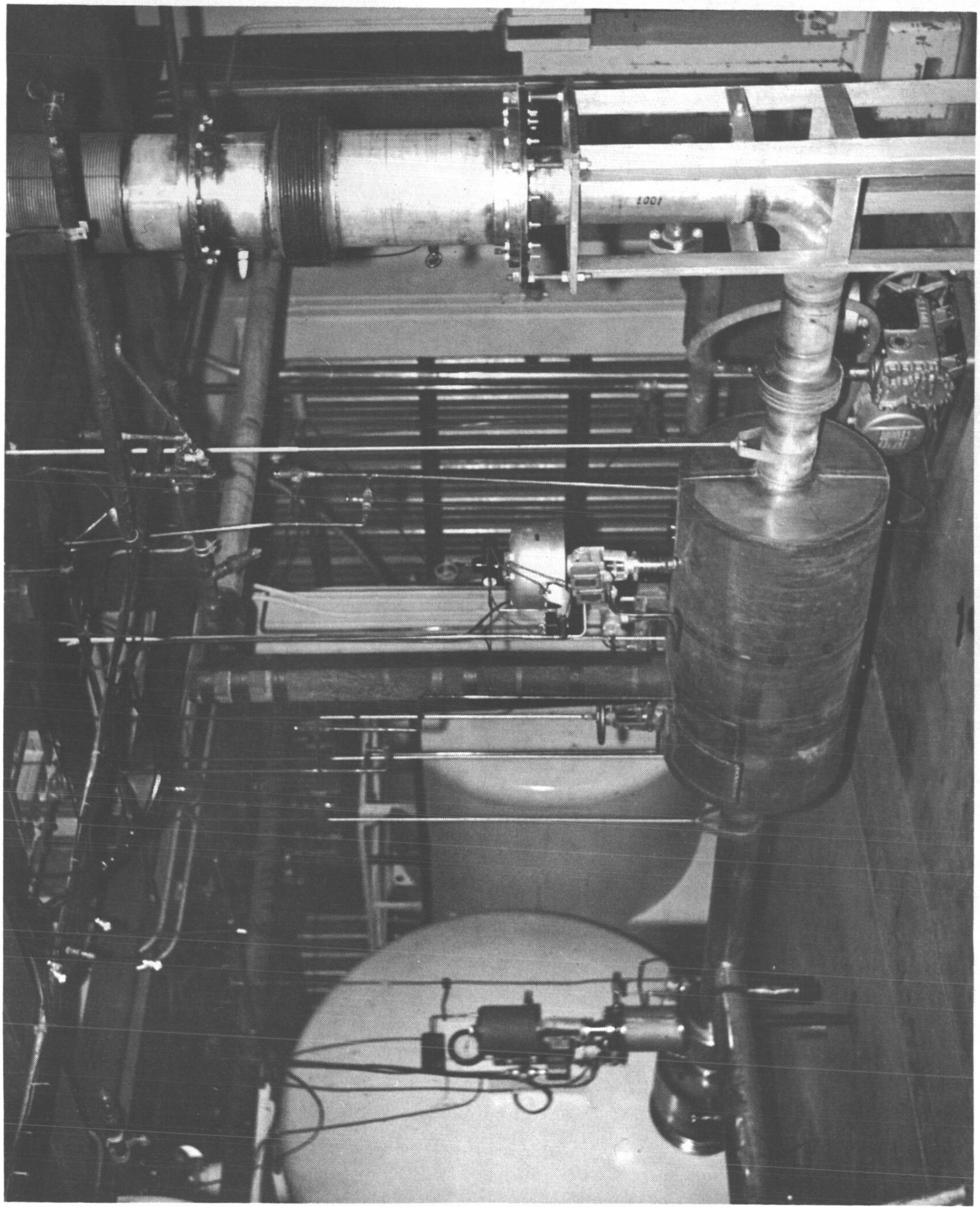
THERMAL TEST FACILITY
PRESSURIZATION CONTROL SYSTEM

APPENDIX D

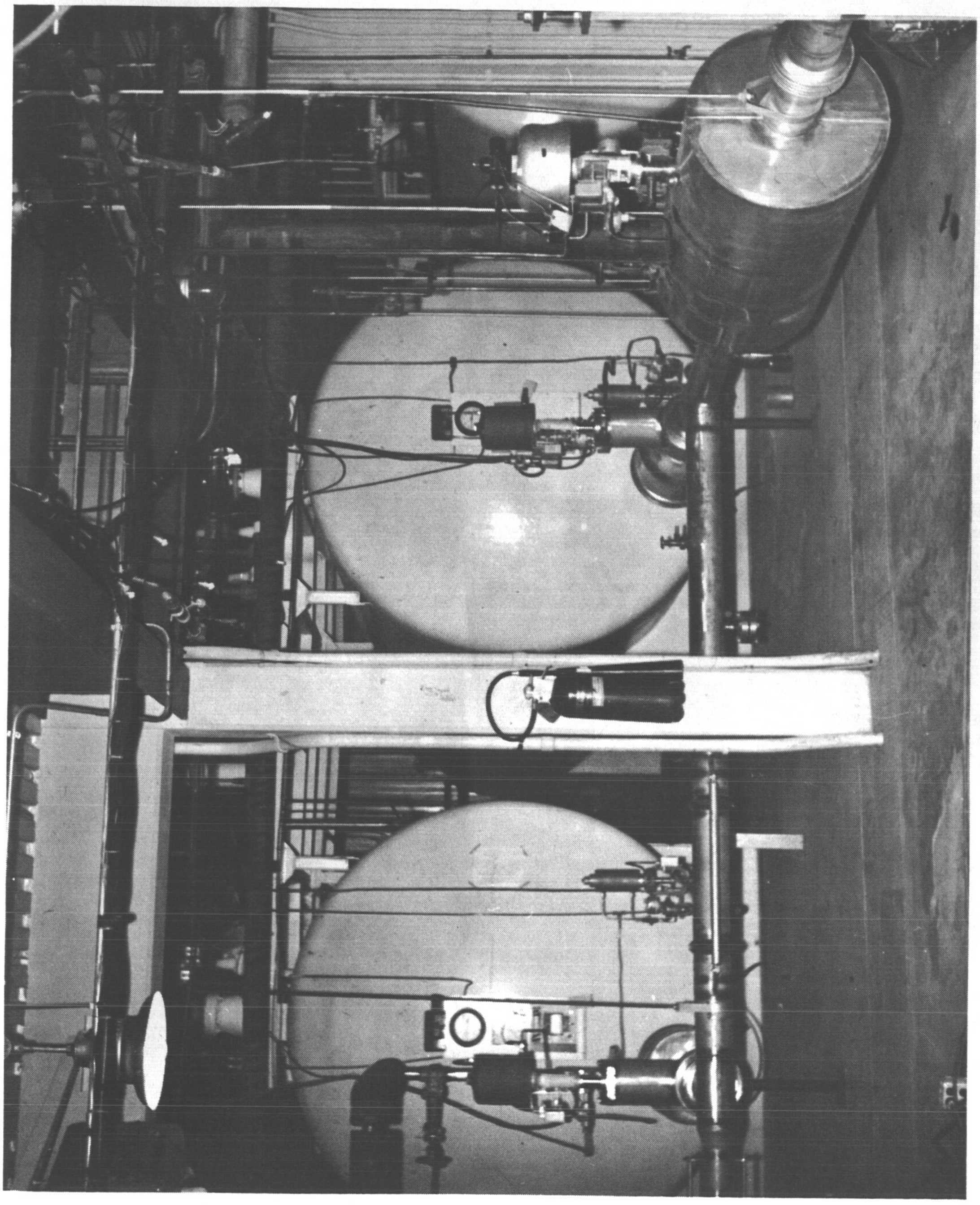
THERMAL TEST FACILITY PHOTOGRAPHS

Pages 80.0 - 91.0

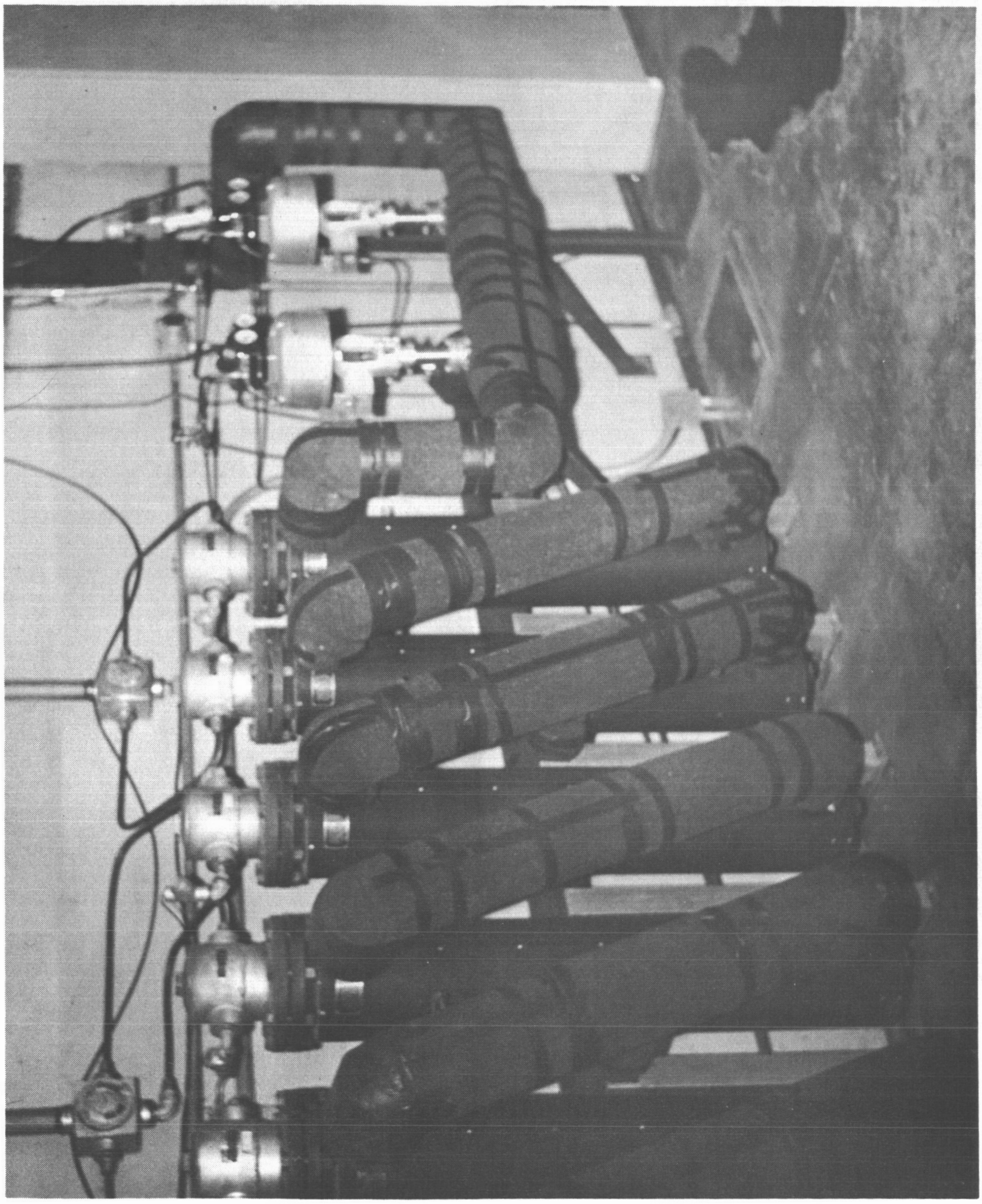
THERMAL TEST FACILITY DURING OPERATIONS



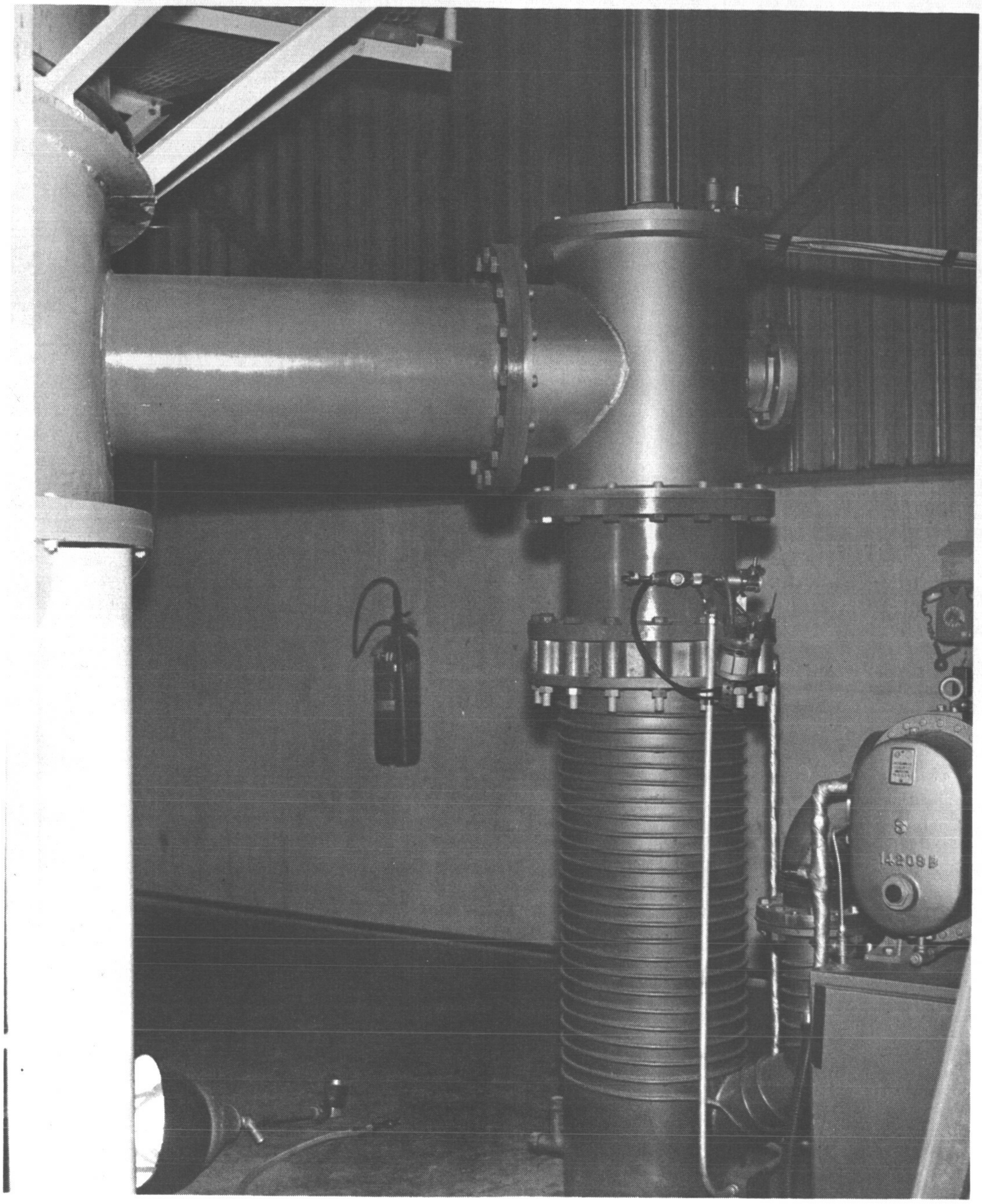
PROPELLANT FLOW CONTROL SYSTEM



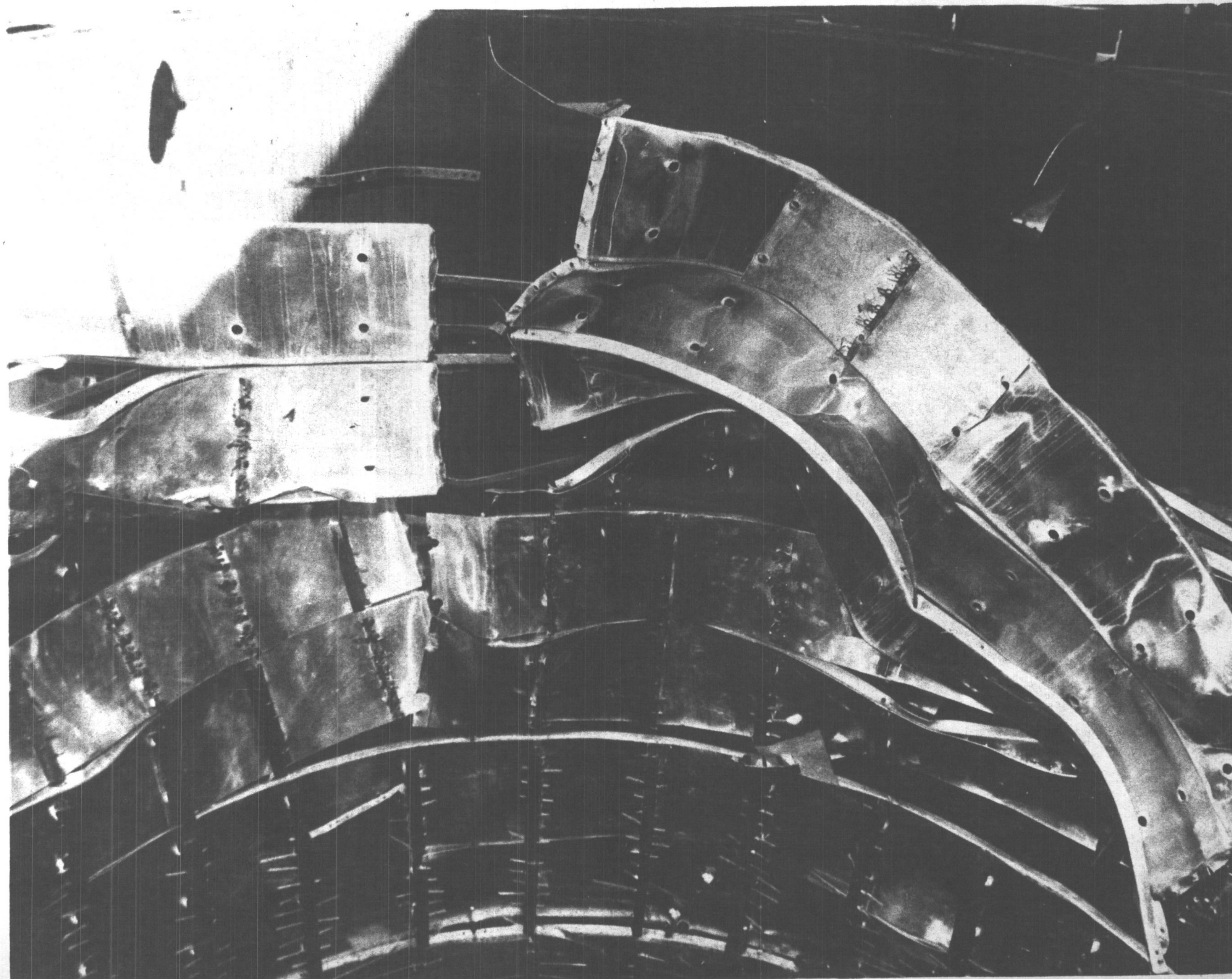
LIQUID HYDROGEN 7000-GALLON STORAGE DEWARS



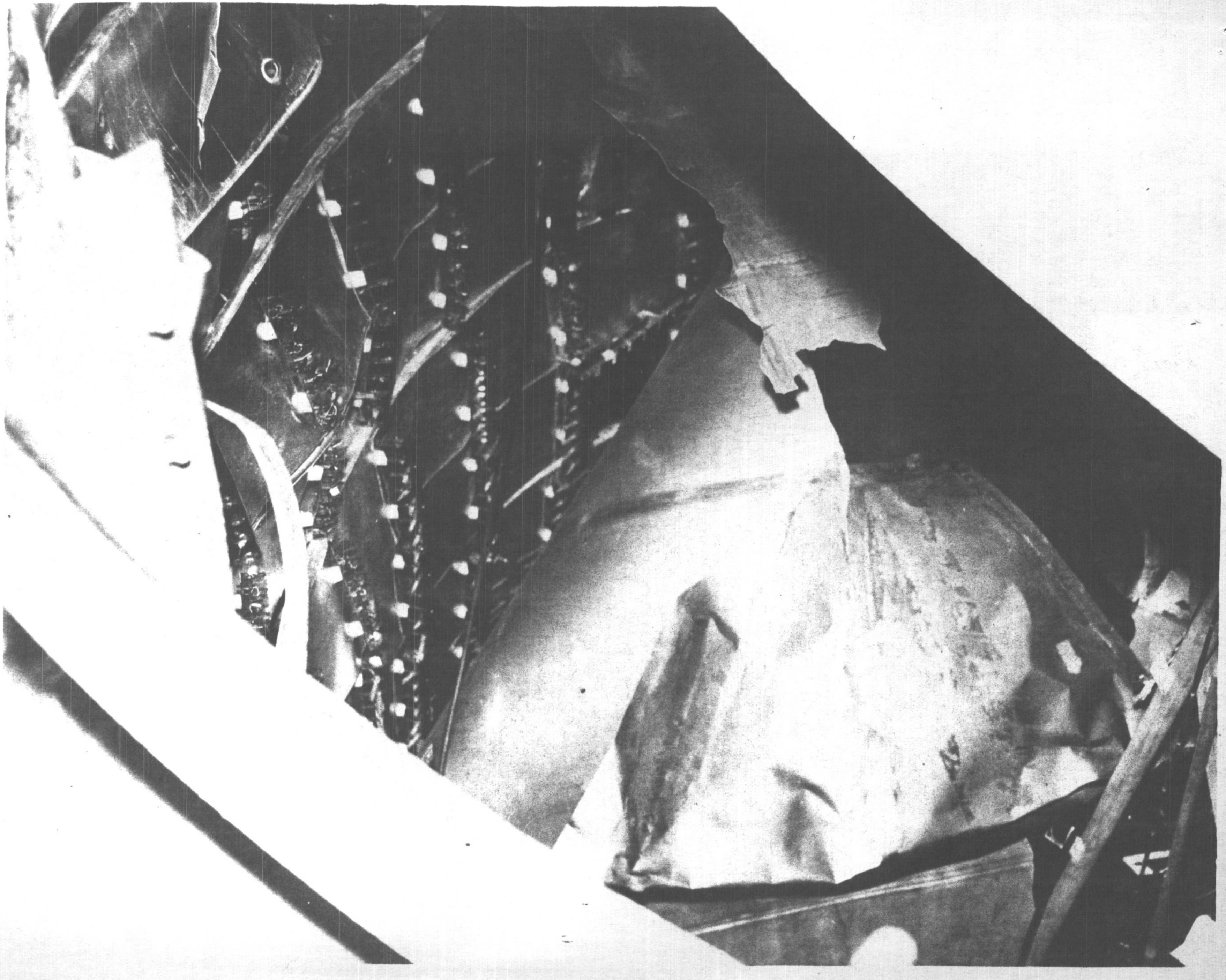
PRESSURIZATION HEAT EXCHANGER SYSTEM



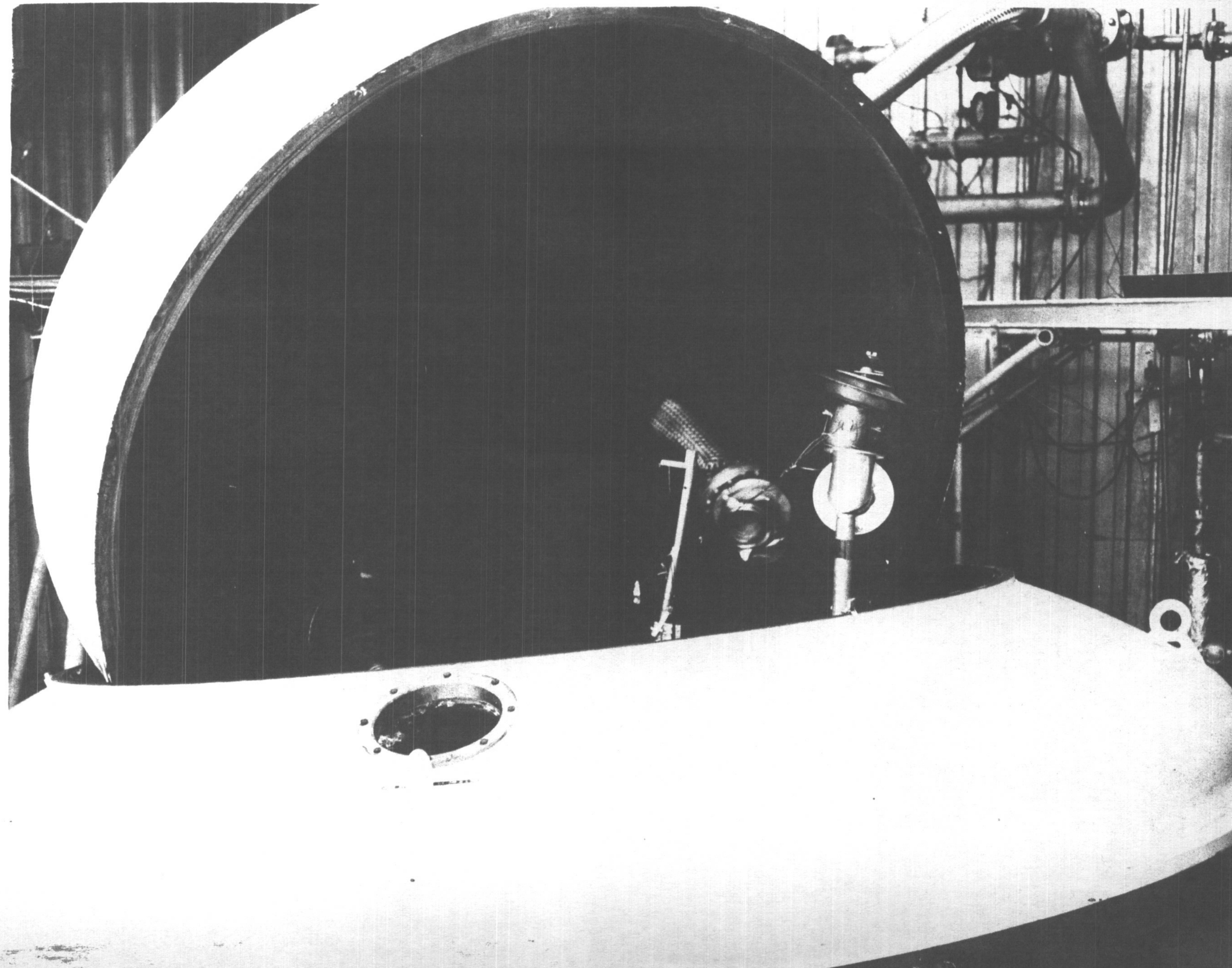
VACUUM BELL PUMPING SYSTEM



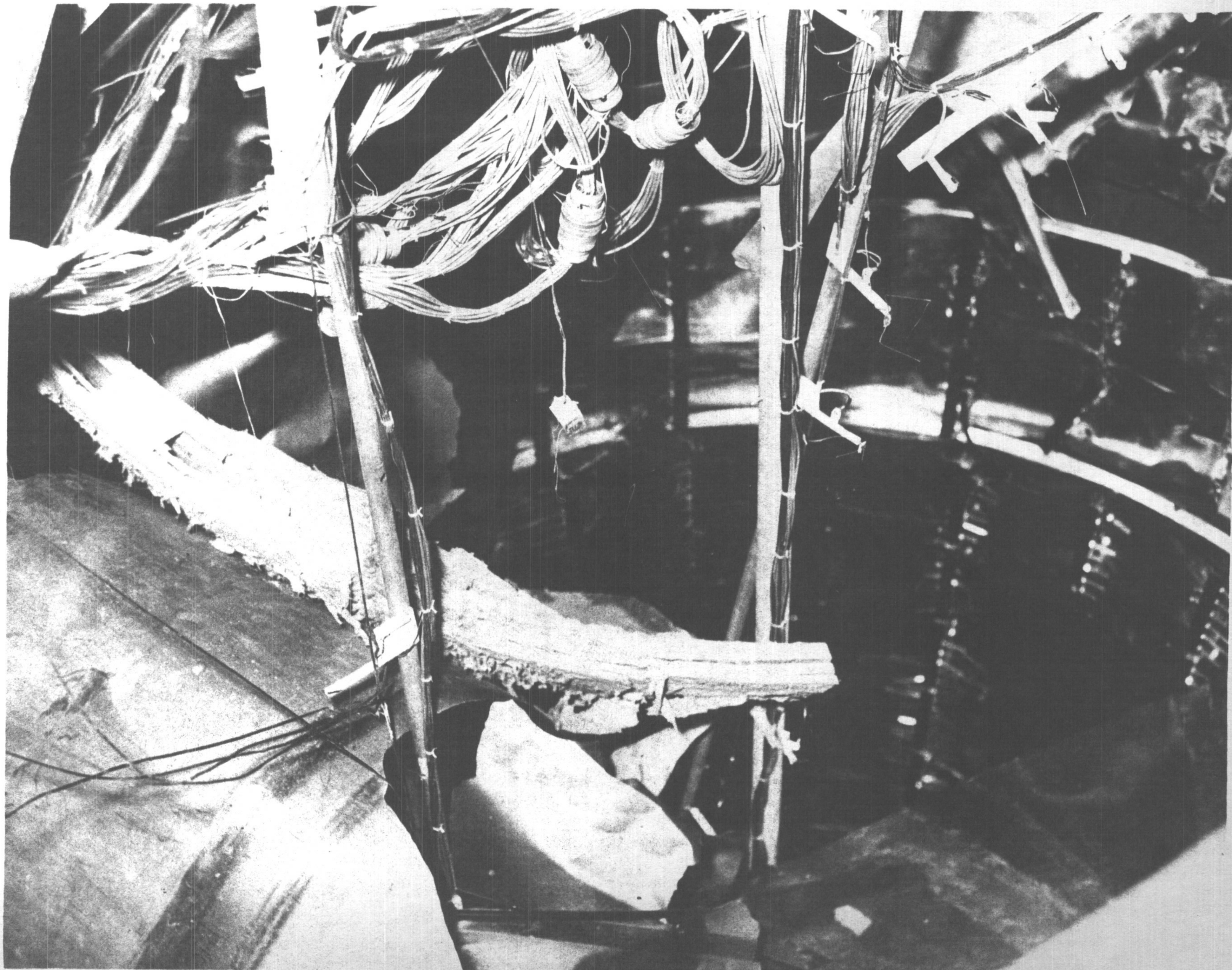
HEATING LAMPS AND REFLECTOR SHIELD DAMAGE



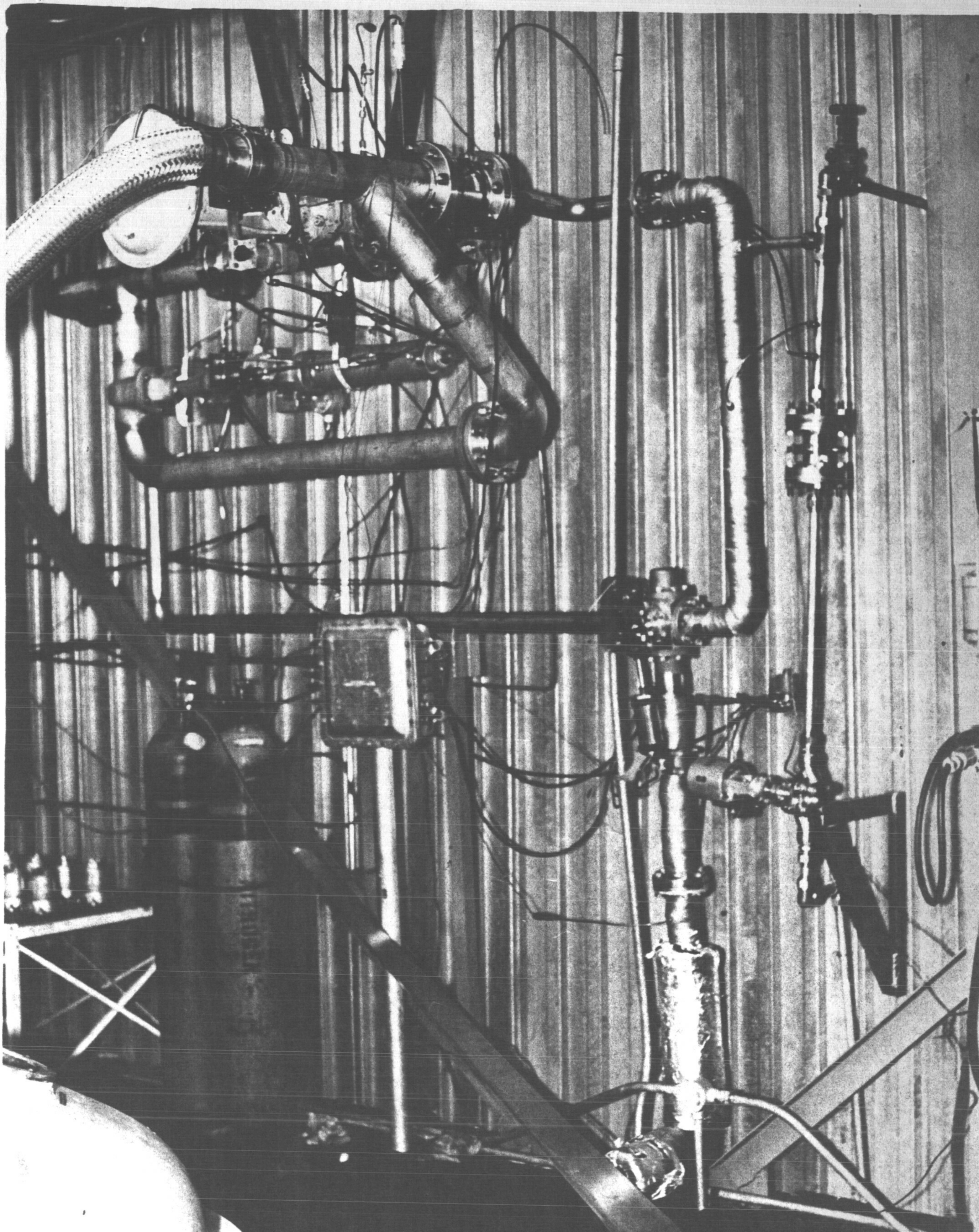
TITANIUM TEST TANK DAMAGE



DIFFUSER AND INSTRUMENTATION RAKE FOLLOWING TANK RUPTURE

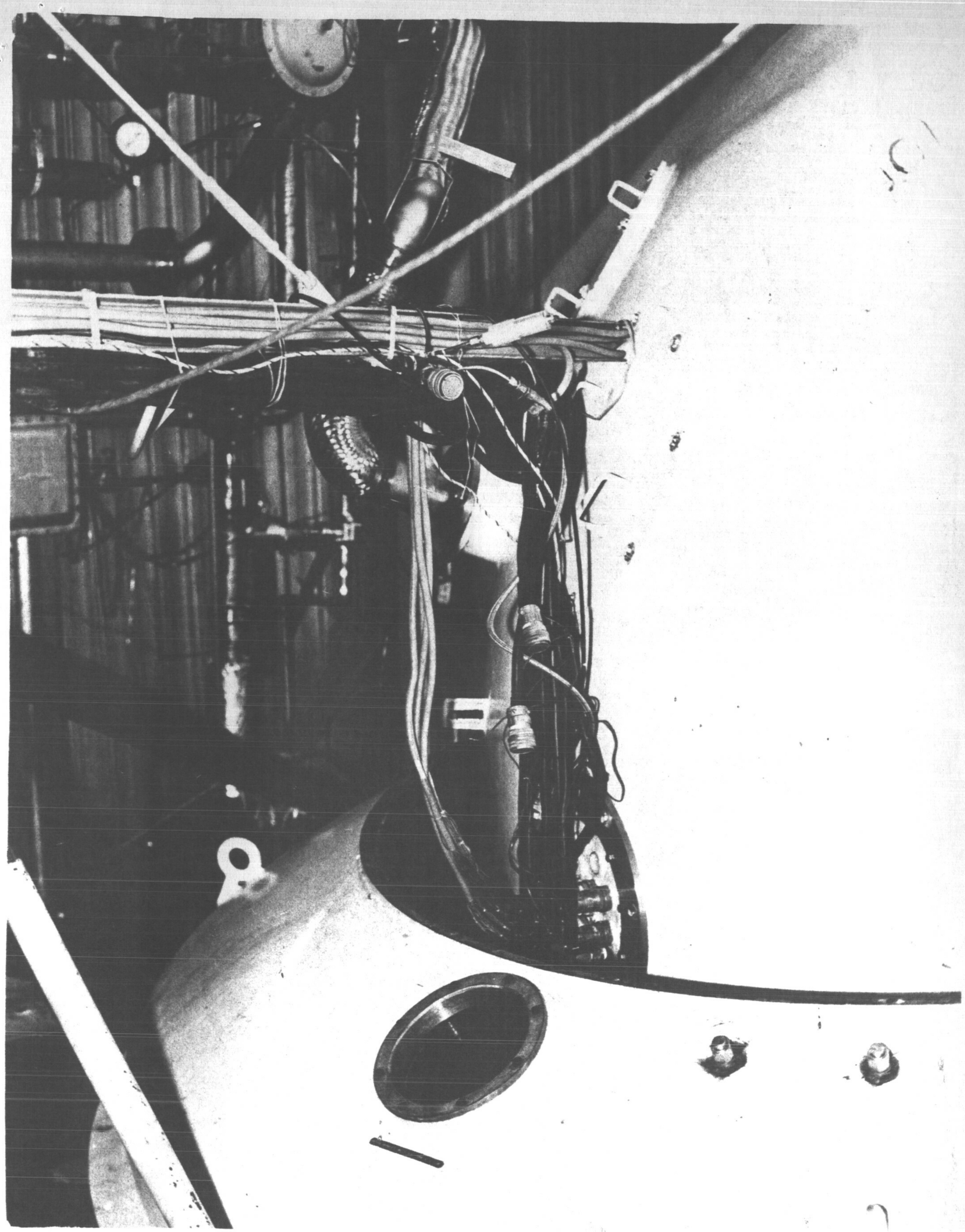


DAMAGED TITANIUM TEST TANK (Note Intact Fast Response Thermocouples)



PRESSURIZATION SYSTEM DAMAGE

THERMAL TEST TOWER



VACUUM BELL COVER DAMAGE

APPENDIX E

TEST EQUIPMENT LIST

Pages 93.0 - 94.0

BEECH TEST REPORT

BEECH AIRCRAFT CORPORATION — ENGINEERING TEST LABORATORIES

REPORT NUMBER	REVISION	PAGE
FR 13632	A	93.0
ISSUE DATE 11-25-64	REVISION DATES "A" 5/5/65	

TEST EQUIPMENT

Item No.	Name of Equipment	Vendor	Model or Part No.	Serial Number	Range, Capacity, Dimensions, Etc.	Accuracy Required	Calib. Every	Last Calib. Date
1	V & P Flowmeter	Waugh	FL-64SF303	10448	0-1250 CFM	± 1%	12 mo.	2-64
2	Prop. Flowmeter	Cox	1-4"x	4859	0-2000 GPM	± 1%	12 mo.	4-64
3	Pre-press Flomtr	Waugh	FL-32SF302	10449	0-280 CFM	± 1%	12 mo.	10-63
4	Magn Tape Recd	Control Data	MTA2-902	108	100 channel	N/A	6 mo.	5-64
5	Events Recorder	Brush Instr.	RE3303-10	273	30 channel	N/A	6 mo.	5-64
6	Temp Recorders	Bristol	1PIG570-21-N3	719016	30 -430°F to 800F	N/A	6 mo.	8-64
7	Monitor Scope	Int. T & T	MMS-1DBX3	307	100 channel	N/A	6 mo.	8-64
8	Dome Controller	Grove	GBX206N3	R79593	5-1500 PSI	± 1%	13 wks	7-64
9	Press Controller	Honeywell	704P2-S391	43003	0-50 Psia	N/A	6 mo.	5-64
10	Press Controller	Honeywell	704P2-S391	43002	0-60 Psia	N/A	6 mo.	5-64
11	Temp Controller	Honeywell	152P13-PS	43001	150°F to -350°F	N/A	6 mo.	5-64
12	T/C Ref. System	Jos. Kaye & Co	RJA48C	ED300	32°	0.1°	13 wks	8-64
13	T/C Ref. System	Thermoelectric	N/A	H992	150°	0.1°	13 wks	8-64
14	MV Potentiometer	Leeds & Northrup	8686	N/A	-10 MV to 100.1 MV	± 0.05	6 mo.	8-64
15	Mg. Amplifiers	Acrogmag	190	42160 42200	Gain=3.84 Linear 6.5mv in 25mv out	± 1.0	6 mo.	6-64
16	Vacuum Gage	Hastings	CV1PV	138 111	0-1000 Microns 0-1000 Microns	10%	13 wks	5-64
17	Vacuum Gage	Hastings	CV1PV	112	0-1000 Microns	10%	13 wks	5-64
18	Vacuum Gage	Hastings	DV4M	N/A	0-20 MM Hg	10%	13 wks	5-64
19	Vacuum Gage	Hastings	DV5M	N/A	0-100 Microns	10%	13 wks	5-64
20	Press Transducer	Statham	PL235TC-350	8696	0-50 PSIA	± 1%	13 wks	7-64
21	Press Transducer	Statham	PA24TC-50	5917	0-50 PSIA	± 1%	13 wks	7-64
22	Press Transducer	Statham	PA24TC-350	5979	0-50 PSIA	± 1%	13 wks	7-64
23	Thermocouples	Beech Aircraft	N/A	1 to 40	Cu - Con	63% Chg. in 2 Sec	N/A	N/A
24	Temp. Sensors	Texas Instr.	N/A	454-60 479-83 488-515	7.5 ohms ±1 ohm 400° 35 ohms ±1.5ohm 200°	±1 ohm ± 1.5 ohm	N/A	N/A
25	Carbon Res.	Ohmite	N/A	N/A	1/10 Watt	± 1%	N/A	N/A
26	Thermocouples	Beech Aircraft	N/A	N/A	Cu - Con	± 5%	N/A	N/A
27	Pressure Switch	Neltron Corp.	436-15L-27	1	15 - 60 PSIA	± 1%	N/A	N/A
28	Guardsmen Contr.	West Instr Co.	N/A	N/A	0-1000°F	± 1%	12 mo.	10-6[illegible]

BEECH TEST REPORT

BEECH AIRCRAFT CORPORATION

Report Number: FR 13632

Issue Date: 11-25-64

"A"

TEST EQUIPMENT

Item No.	Name of Equipment	Vendor	Model or Part No.	Serial Number	Range, Capacity, Dimensions, Etc.	Accuracy Required	Calib. Every	Last Calib. Date
29	Pressure Gages	Acragage	2365X	N/A	0-160 psi	± 1%	13 wks	6-64
30	Ignitron Power Controllers	Research, Inc	6150A	1-16	350 KVA for 5 min 175 KVA continuous	± 1%	N/A	N/A
31	Heat Control Console	" "	CC6280-9B	N/A	N/A	N/A	N/A	N/A
32	Heat Transfer Computers	" "	CTP6249	N/A	-430°F to 800°F	± 1%	N/A	N/A
33	Jet Diffusion Pump	F.S. Stokes	160-16"	C87273-11	9500 CFM	N/A	N/A	N/A
34	Mech Booster Pump	" "	1721	C3136-40	1300 CFM	N/A	N/A	N/A
35	Flow Control Indicating Recr.	Foxboro	65PX-CHW	N/A	0-2000 GPM	± 1%	12 mo.	10-63
36	Flow Control Indicating Contr.	"	624P	N/A	0-2000 GPM	± 1%	12 mo.	10-63
37	Turbine Flow Transmitter	"	WFB-64-15	N/A	200-2000 GPM	± 1%	12 mo.	10-63
38	Freq. Converter	"	WFB305-5-15	N/A	Input 0-5 VDC Output 10-50 MA	± 1%	12 mo.	10-63

APPENDIX F

INSTRUMENTATION LOCATIONS

Page 96.0

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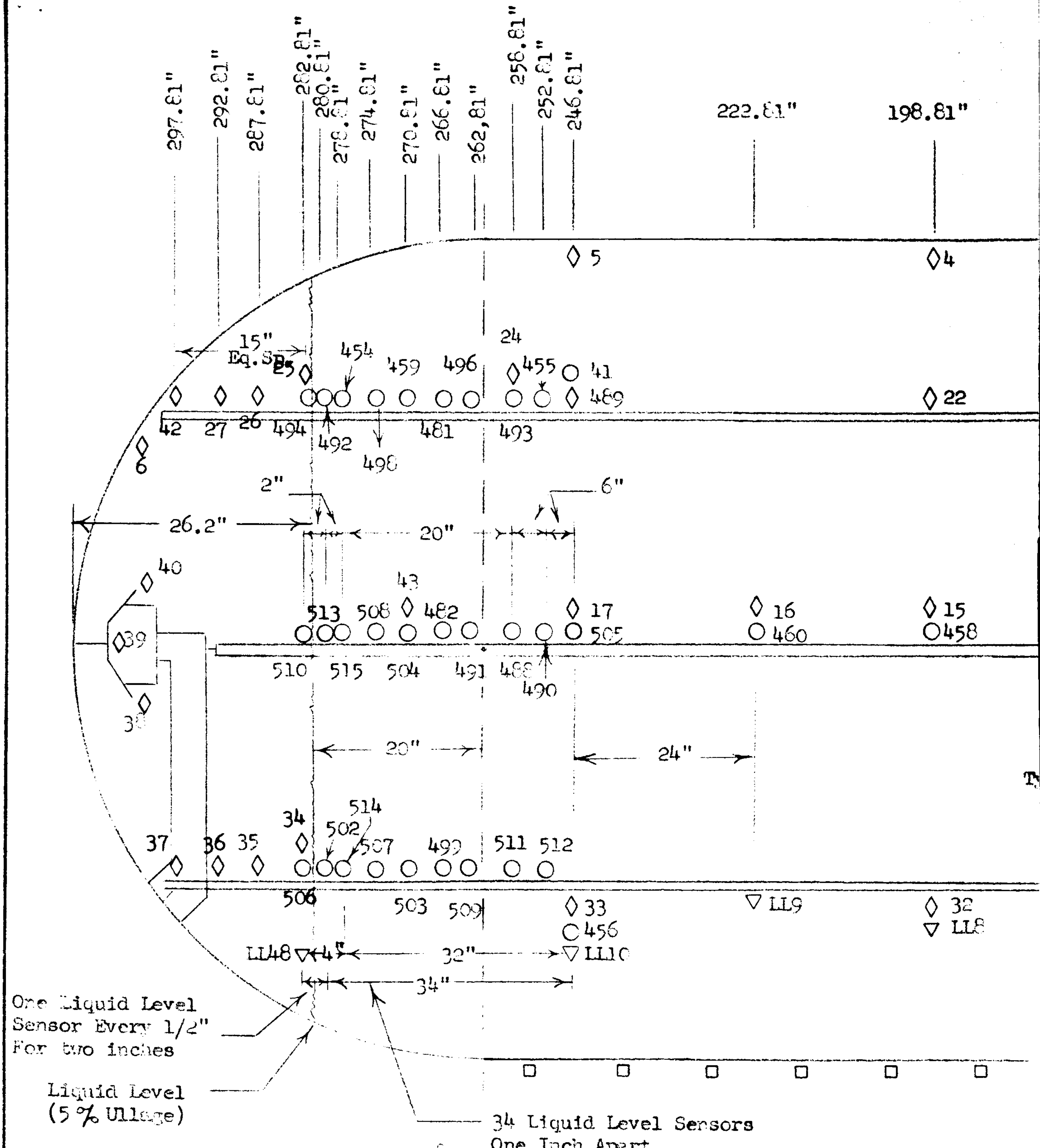
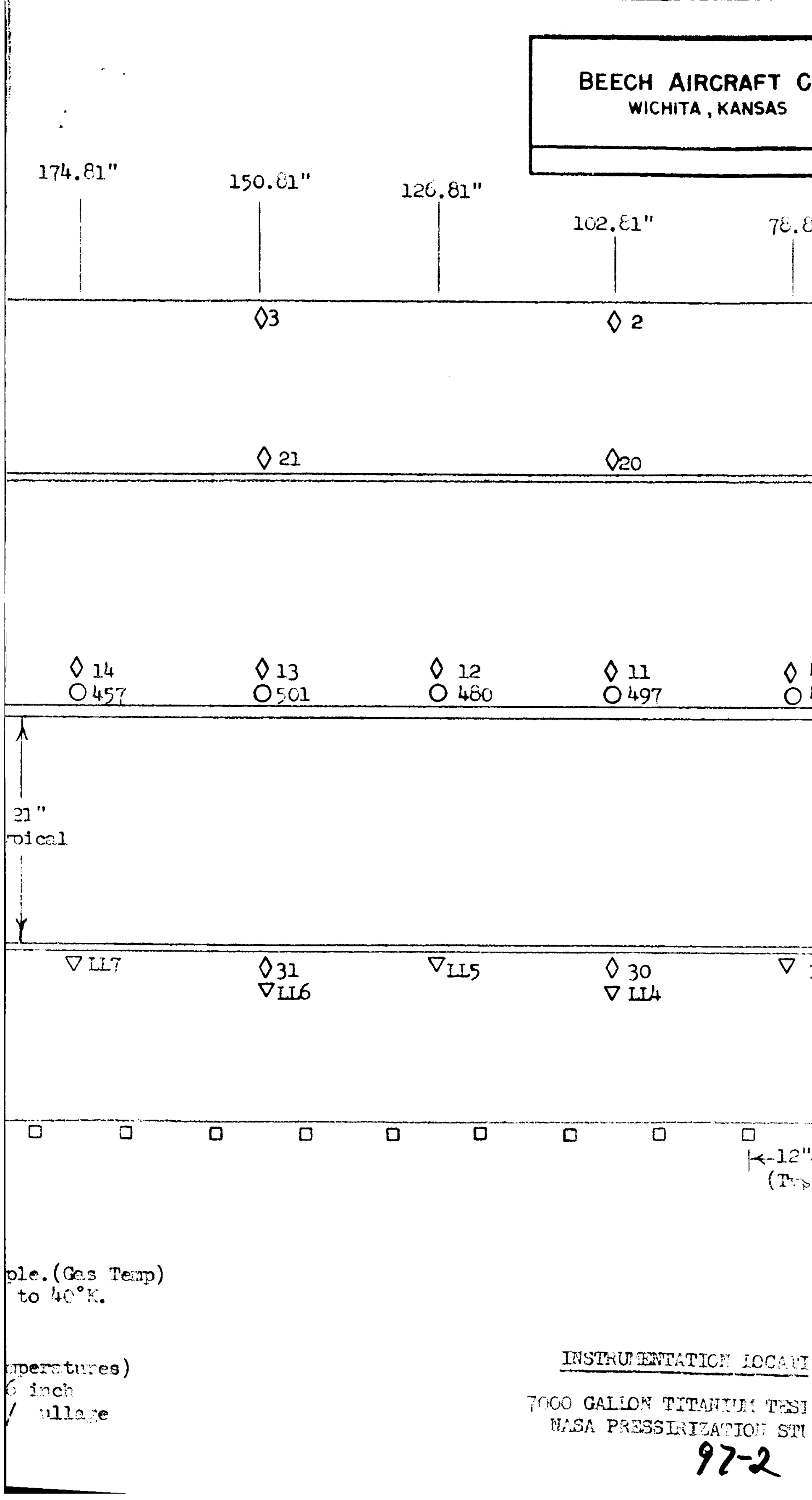


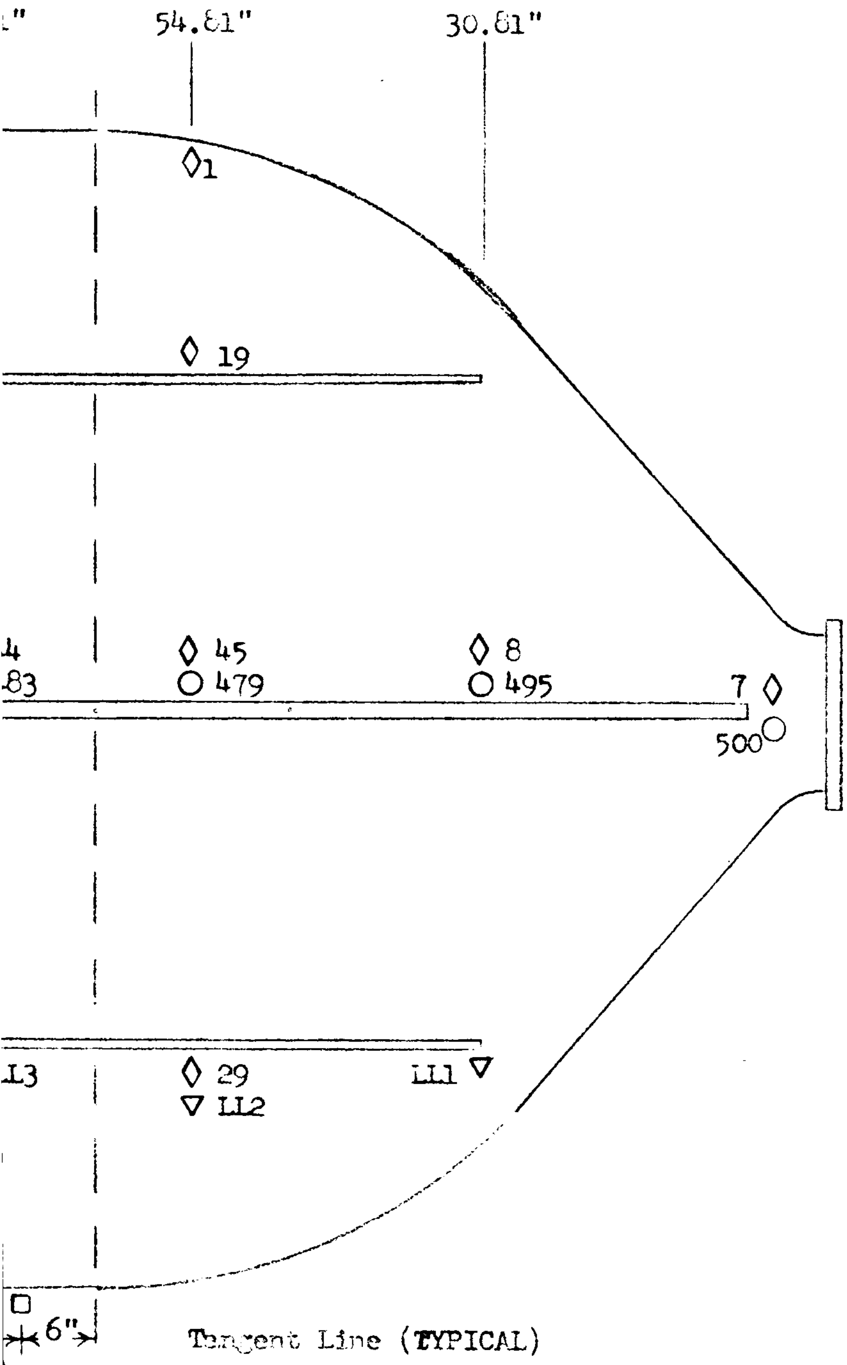
Notes:

1. The symbol ◇ designates a fast response copper - constantan type thermoc
2. The symbol ○ designates a germanium therometer sensor calibrated from 20 (Liquid Hydrogen Temperature)
3. The symbol ▽ designates a 1/10 watt carbon resistor liquid level sensor
4. The symbol □ designates a thermocouple, copper - constantan type. (Skin
5. Tank Dimensions: 92.4 inch inside diameter; cylinder 192.0 inches long; radius hemispherical ends; lower end is tangent to a conical section. The is at the liquid level.



BEECH AIRCRAFT C
WICHITA, KANSAS
174.81"
150.81"
126.81"
102.81"
78.8
3
2
21
20
14
457
13
501
12
480
11
497
21"
pical
LL7
31
LL6
LL5
30
LL4
12"
ple. (Gas Temp)
to 40°K.
mperatures)
6 inch
ullage
INSTRUMENTATION LOCATI
7000 GALLON TITANIUM TEST
NASA PRESSURIZATION STU
97-2

ORP.	BY Al Lowrie	REPORT NASA Pressurization Study
	CK	
	DATE 12 April 1964	PAGE



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TANK
Y

APPENDIX G

INSTRUMENTATION CHANNEL ASSIGNMENTS

Pages

98.0 - 104.0

NASA PRESSURIZATION STUDY
Instrumentation Channel Assignment

CHANNEL NO.	FUNCTION	TEST PROBE	LOCATION
1	Time		
2	Zero Reference		
3	Full Scale Reference		
4	Temperature	Germanium 500	Outflow Line
5	Temperature	Germanium 495	Center Pole 30.81 inch
6	Temperature	Germanium 479	Center Pole 54.81 inch
7	Temperature	Germanium 483	Center Pole 78.81 inch
8	Temperature	Germanium 497	Center Pole 102.81 inch
9	Temperature	Germanium 480	Center Pole 126.81 inch
10	Temperature	Germanium 501	Center Pole 150.81 inch
11	Temperature	Germanium 457	Center Pole 174.81 inch
12	Temperature	Germanium 458	Center Pole 198.81 inch
13	Temperature	Germanium 460	Center Pole 222.81 inch
14	Temperature	Germanium 456	Left Pole 246.81 inch
15	Temperature	Germanium 505	Center Pole 246.81 inch
16	Temperature	Germanium 489	Right Pole 246.81 inch
17	Temperature	Germanium 512	Left Pole 252.81 inch
18	Temperature	Germanium 490	Center Pole 252.81 inch
19	Temperature	Germanium 455	Right Leg 252.81 inch
20	Temperature	Germanium 511	Left Leg 258.81 inch
21	Temperature	Germanium 488	Center Pole 258.81 inch
22	Temperature	Germanium 493	Right Pole 258.81 inch

NASA PRESSURIZATION STUDY (Cont.)

CHANNEL NO.	FUNCTION	TEST PROBE	LOCATION
23	Temperature	Germanium 509	Left Pole 262.81 inch
24	Temperature	Germanium 491	Center Pole 262.81 inch
25	Temperature	Germanium 496	Right Pole 262.81 inch
26	Temperature	Germanium 499	Left Pole 266.81 inch
27	Temperature	Germanium 482	Center Pole 266.81 inch
28	Temperature	Germanium 481	Right Pole 266.81 inch
29	Temperature	Germanium 503	Left Pole 270.81 inch
30	Temperature	Germanium 504	Center Pole 270.81 inch
31	Temperature	Germanium 459	Right Pole 270.81 inch
32	Temperature	Germanium 507	Left Pole 274.81 inch
33	Temperature	Germanium 508	Center Pole 274.81 inch
34	Temperature	Germanium 498	Right Pole 274.81 inch
35	Temperature	Germanium 514	Left Pole 278.81 inch
36	Temperature	Germanium 515	Center Pole 278.81 inch
37	Temperature	Germanium 454	Right Pole 278.81 inch
38	Temperature	Germanium 502	Left Pole 280.81 inch
39	Temperature	Germanium 513	Center Pole 280.81 inch
40	Temperature	Germanium 492	Right Leg 280.81 inch
41	Temperature	Germanium 506	Left Pole 282.81 inch
42	Temperature	Germanium 510	Center Pole 282.81 inch
43	Temperature	Germanium 494	Right Pole 282.81 inch

NASA PRESSURIZATION STUDY (Cont.)

CHANNEL NO.	FUNCTION	TEST PROBE	LOCATION
44	Temperature	Thermocouple 7	Outflow Line
45	Temperature	Thermocouple 8	Center Pole 30.81 inch
46	Temperature	Thermocouple 29	Left Pole 54.81 inch
47	Temperature	Thermocouple 45	Center Pole 54.81 inch
48	Temperature	Thermocouple 19	Right Pole 54.81 inch
49	Temperature	Thermocouple 1	Tank Wall 54.81 inch
50	Temperature	Thermocouple 44	Center Pole 78.81 inch
51	Temperature	Thermocouple 30	Left Pole 102.81 inch
52	Temperature	Thermocouple 11	Center Pole 102.81 inch
53	Temperature	Thermocouple 20	Right Pole 102.81 inch
54	Temperature	Thermocouple 2	Tank Wall 102.81 inch
55	Temperature	Thermocouple 12	Center Pole 126.81 inch
56	Temperature	Thermocouple 31	Left Pole 150.81 inch
57	Temperature	Thermocouple 13	Center Pole 150.81 inch
58	Temperature	Thermocouple 21	Right Pole 150.81 inch
59	Temperature	Thermocouple 3	Tank Wall 150.81 inch
60	Temperature	Thermocouple 14	Center Pole 174.81 inch
61	Temperature	Thermocouple 32	Left Pole 198.81 inch
62	Temperature	Thermocouple 15	Center Pole 198.81 inch
63	Temperature	Thermocouple 22	Right Pole 198.81 inch
64	Temperature	Thermocouple 4	Tank Wall 198.81 inch

NASA PRESSURIZATION STUDY (Cont.)

CHANNEL NO.	FUNCTION	TEST PROBE	LOCATION
65	Temperature	Thermocouple 16	Center Pole 222.81 inch
66	Temperature	Thermocouple 33	Left Pole 246.81 inch
67	Temperature	Thermocouple 17	Center Pole 246.81 inch
68	Temperature	Thermocouple 41	Right Pole 246.81 inch
69	Temperature	Thermocouple 5	Tank Wall 246.81 inch
70	Temperature	Thermocouple 24	Right Pole 258.81 inch
71	Temperature	Thermocouple 43	Center Pole 270.81 inch
72	Temperature	Thermocouple 34	Left Pole 282.81 inch
73	Temperature	Thermocouple 25	Right Pole 282.81 inch
74	Temperature	Thermocouple 35	Left Pole 287.81 inch
75	Temperature	Thermocouple 26	Right Pole 287.81 inch
76	Temperature	Thermocouple 36	Left Pole 292.81 inch
77	Temperature	Thermocouple 27	Right Pole 292.81 inch
78	Temperature	Thermocouple 37	Left Pole 297.81 inch
79	Temperature	Thermocouple 42	Right Pole 297.81 inch
80	Temperature	Thermocouple 6	Tank Wall 301.81 inch
81	Temperature	Thermocouple 38	Diffuser
82	Temperature	Thermocouple 39	Diffuser
83	Temperature	Thermocouple 40	Diffuser
84	T2 Buildup Temperature	CU-Con	150^{o} Ref.

NASA PRESSURIZATION STUDY (Cont.)

CHANNEL NO.	FUNCTION	TEST PROBE	LOCATION
85	Temp. T1 Pre-Pressure	CU-Con	150° Ref
86	Temp. T3 Press-Vent	CU-Con	150° Ref.
87	Pressure Ullage P2	S/N 5979	0 - 50 psia
88	Pre-Pressure P1	S/N 611827	0 - 100 psia
89	Press-Vent P3	S/N 5917	0 - 50 psia
90	Pre-Press. FM1 Flow Rate	S/N 10449	0 - 280 CFM
91	Press-Vent Flow FM3	S/N 10448	0 - 1125 CFM
92	Propellant Flow FM2	S/N 4859	0 - 2000 GPM
93	Switch Trace	Valve PV	
94	Switch Trace	Valve FFC	
95	Switch Trace	Valve PPC	
96	No. 3 Liquid Level	1/10 W. Resistor	78.81 inch
97	No. 10 Liquid Level	1/10 W. Resistor	246.81 inch
98	No. 44 Liquid Level	1/10 W. Resistor	280.81 inch
99	No. 48 Liquid Level	1/10 W. Resistor	282.81 inch

BEECH TEST REPORT

Beech Aircraft Corporation — Environmental Test Laboratories

Document No.	Rev.	Date
FR 13632	A	[illegible]
Issue Date 11-25-64	Revision Date "A" 5/?/65	

NASA PRESSURIZATION STUDY

The following list is the location of the liquid level sensors which will be used to conduct the above-referenced tests. From this list seventeen (17) sensors will be on the Brush recorder and four (4) sensors will be on the monitor scope. All locations are referenced from the bottom edge of the bottom flange on the titanium tank.

Sensor No.	Type Recorder Readout and Channel Number		SENSOR Location (inches)	Temperature -423 °F	
	Brush Record	Monitor Scope		Volume at 12 psia (gallons)	Volume at 30 psia (gallons)
48	Channel 1	Channel 98	282.81	7010.6	7042.2
47			282.31	6998.9	7034.1
46	Channel 2		281.81	6987.2	7020.5
45			281.31	6975.6	7007.9
44	Channel 3	Channel 97	280.31	6963.9	6996.3
43	Channel 4		279.81	6939.7	6973.7
42	Channel 5		278.31	6914.9	6948.2
41			277.81	6889.6	6922.7
40			276.31	6864.4	6894.4
39			275.81	6841.2	6869.5
38			274.81	6814.2	6843.5
37			273.81	6787.2	6816.3
36			272.31	6760.2	6791.4
35			271.81	6732.2	6760.3
34	Channel 6		270.81	6704.2	6728.5
33			269.81	6676.2	6700.2
32			268.81	6648.2	6674.3
31			267.81	6619.4	6648.5
30			266.81	6590.6	6620.2
29			265.81	6561.8	6590.9
28			264.81	6533.0	6562.1
27			263.81	6504.2	6533.3
26			262.81	6475.4	6504.5
25			261.81	6446.6	6475.7
24			260.81	6417.7	6446.7
23			259.31	6388.8	6417.7
22	Channel 7		258.81	6359.9	6388.6
21			257.81	6331.0	6359.6
20			256.31	6302.2	6330.6
19			255.81	6273.2	6301.6
18			254.81	6244.4	6272.6
17			253.31	6215.5	6243.5
16			252.31	6186.6	6214.5
15			251.31	6157.7	[illegible]
14			250.31	6128.8	6156.6
13			249.31	6099.9	6127.5

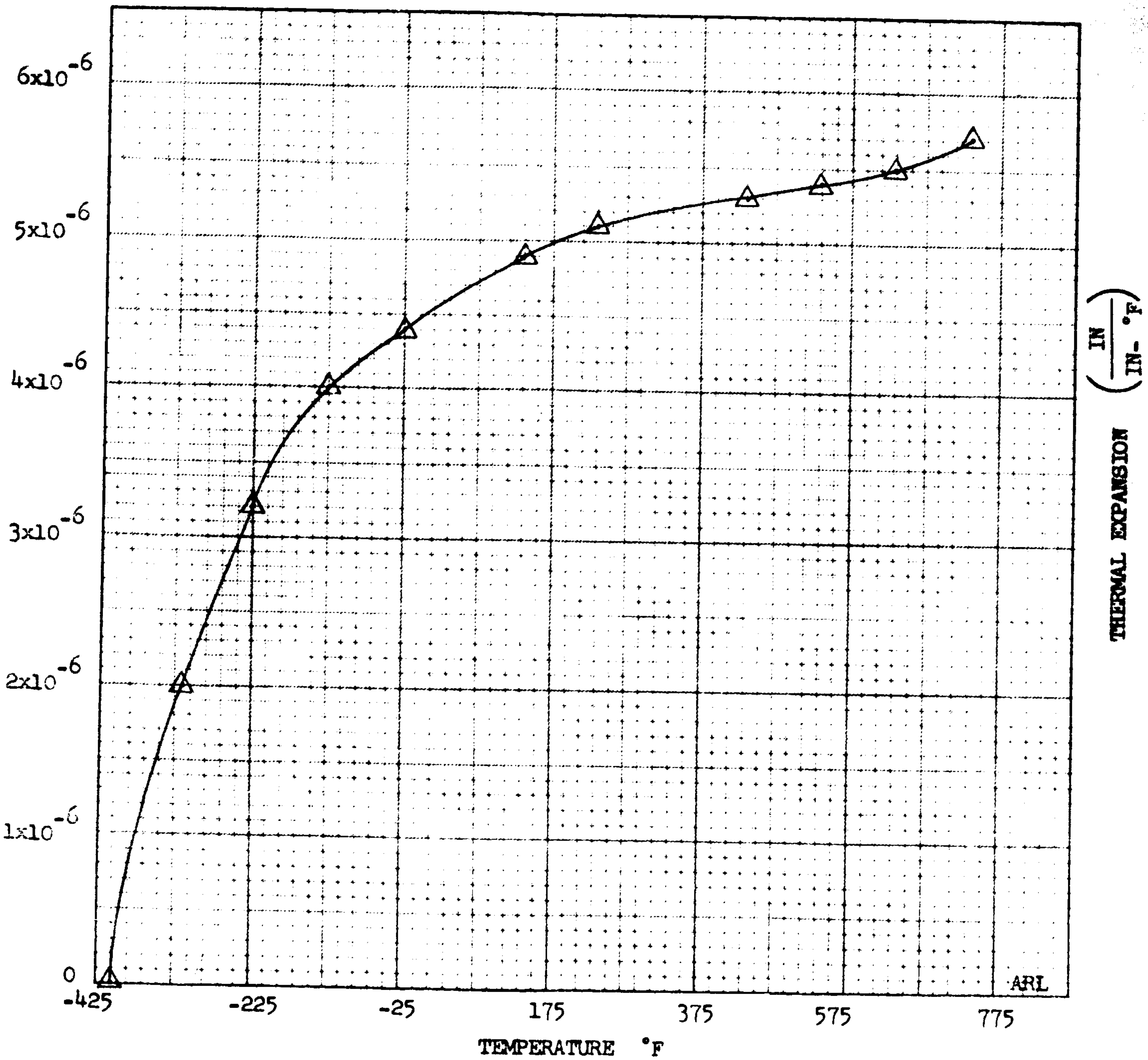
Sensor No.	Type Recorder Readout and Channel Number		SENSOR Location (inches)	Temperature	-423°F
	Brush Record	Monitor Scope		Volume at 12 psia (gallons)	Volume at 30 psia (gallons)
12			248.81	6071.1	6098.4
11			247.81	6042.1	6069.4
10	Channel 8	Channel 96	246.81	6013.3	6040.4
9	Channel 9		222.81	5319.9	5343.9
8	Channel 10		198.81	4626.5	4647.4
7	Channel 11		174.81	3933.2	3950.9
6	Channel 12		150.81	3239.8	3254.5
5	Channel 13		126.81	2546.5	2558.0
4	Channel 14		102.81	1853.1	1861.5
3	Channel 15	Channel 95	78.81	1159.7	1165.1
2	Channel 16		54.81	463.2	469.7
1	Channel 17		30.81	72.3	74.5

APPENDIX H

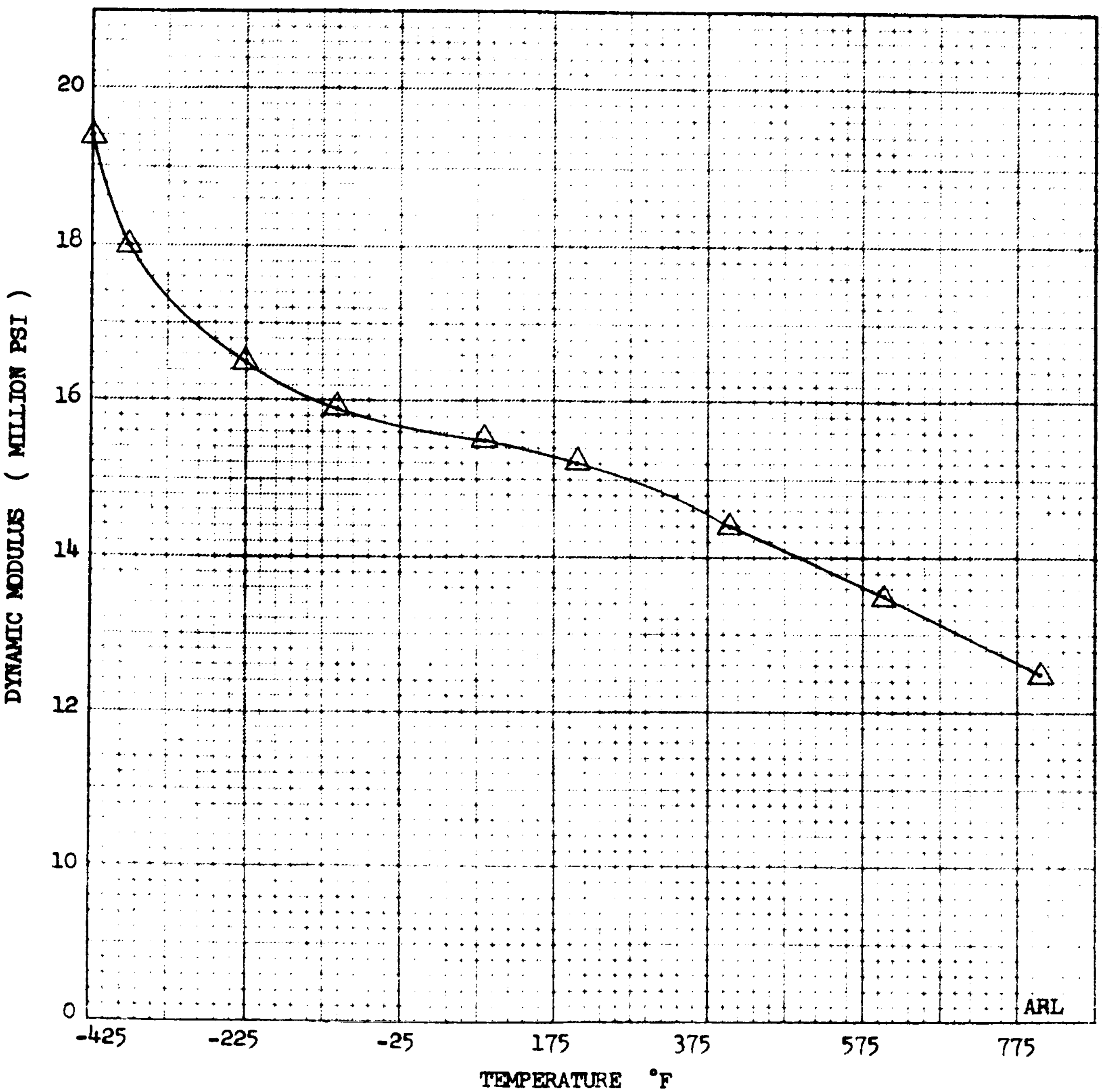
PROPERTIES OF 6Al-4V TITANIUM

Pages

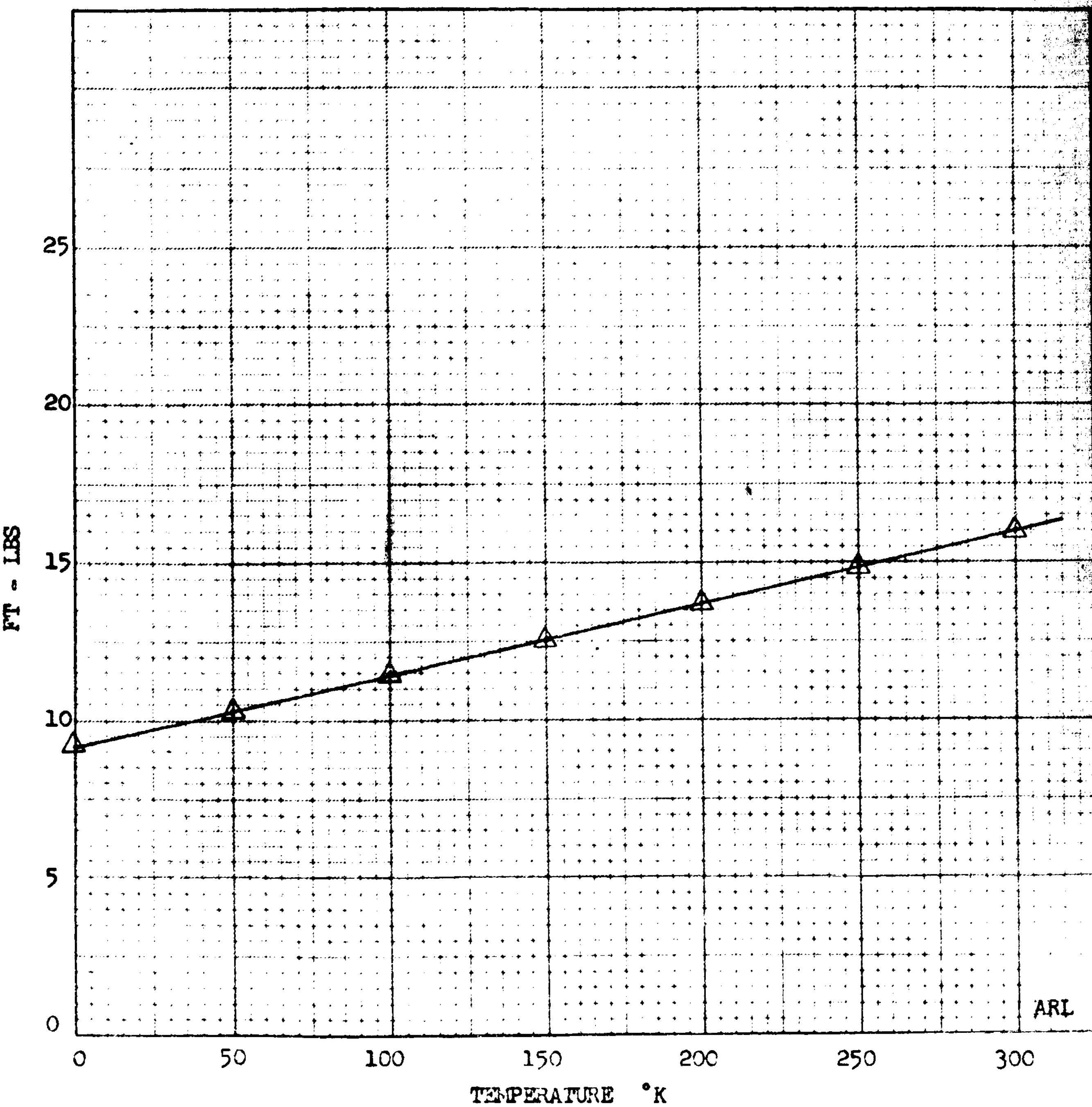
106.0 - 112.0



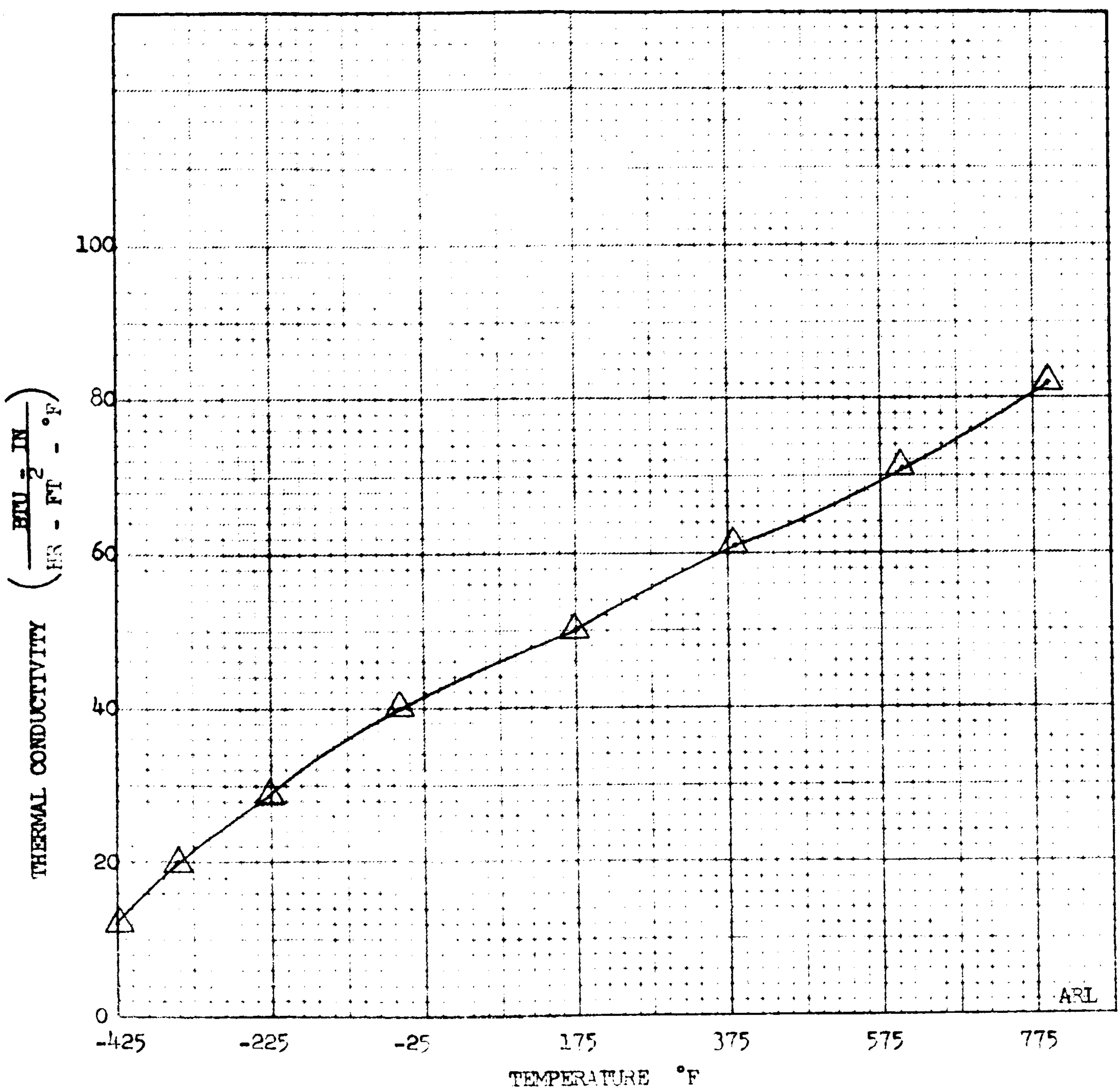
THERMAL EXPANSION OF TITANIUM



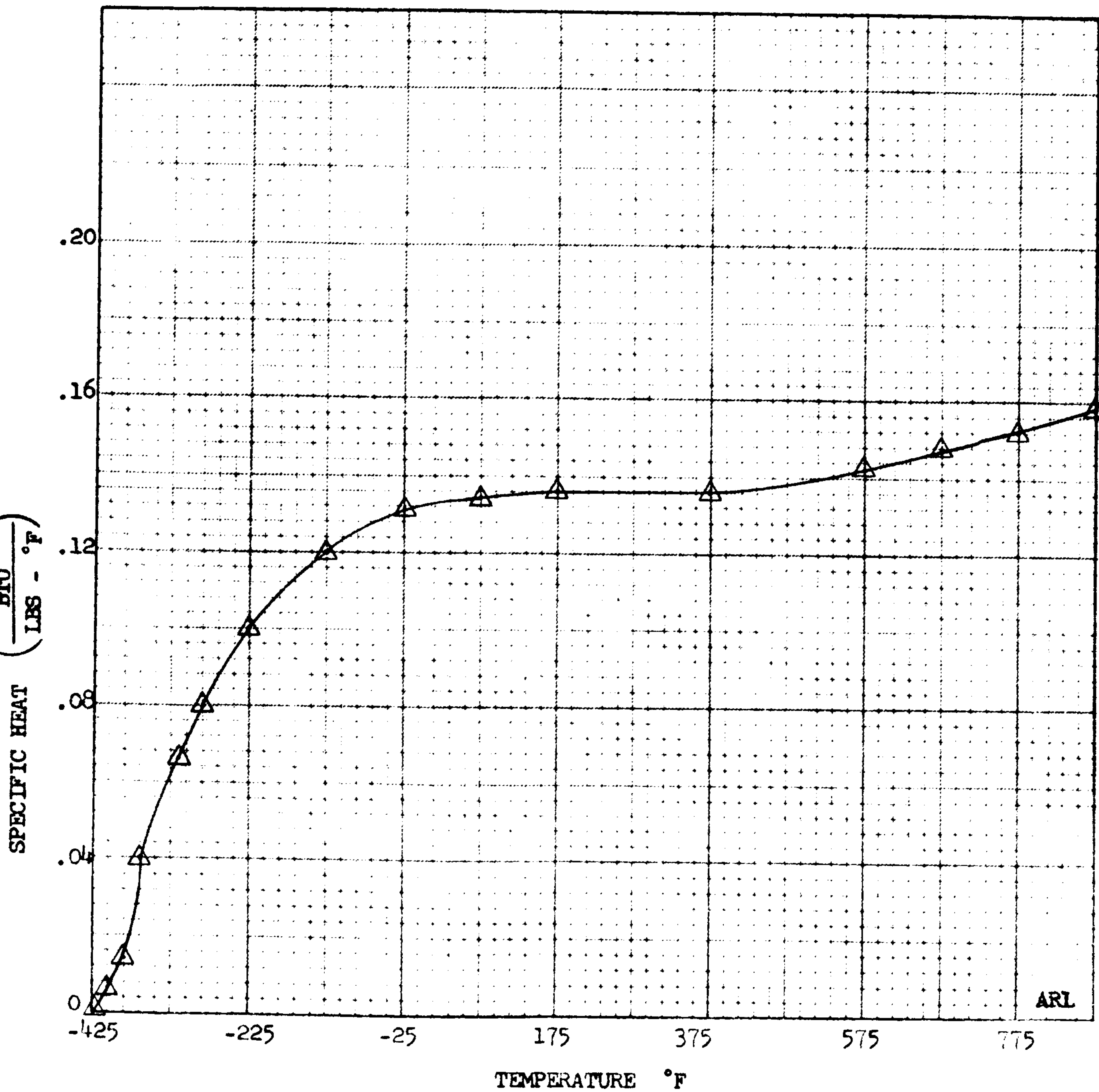
YOUNGS MODULUS OF 6Al-4V TITANIUM



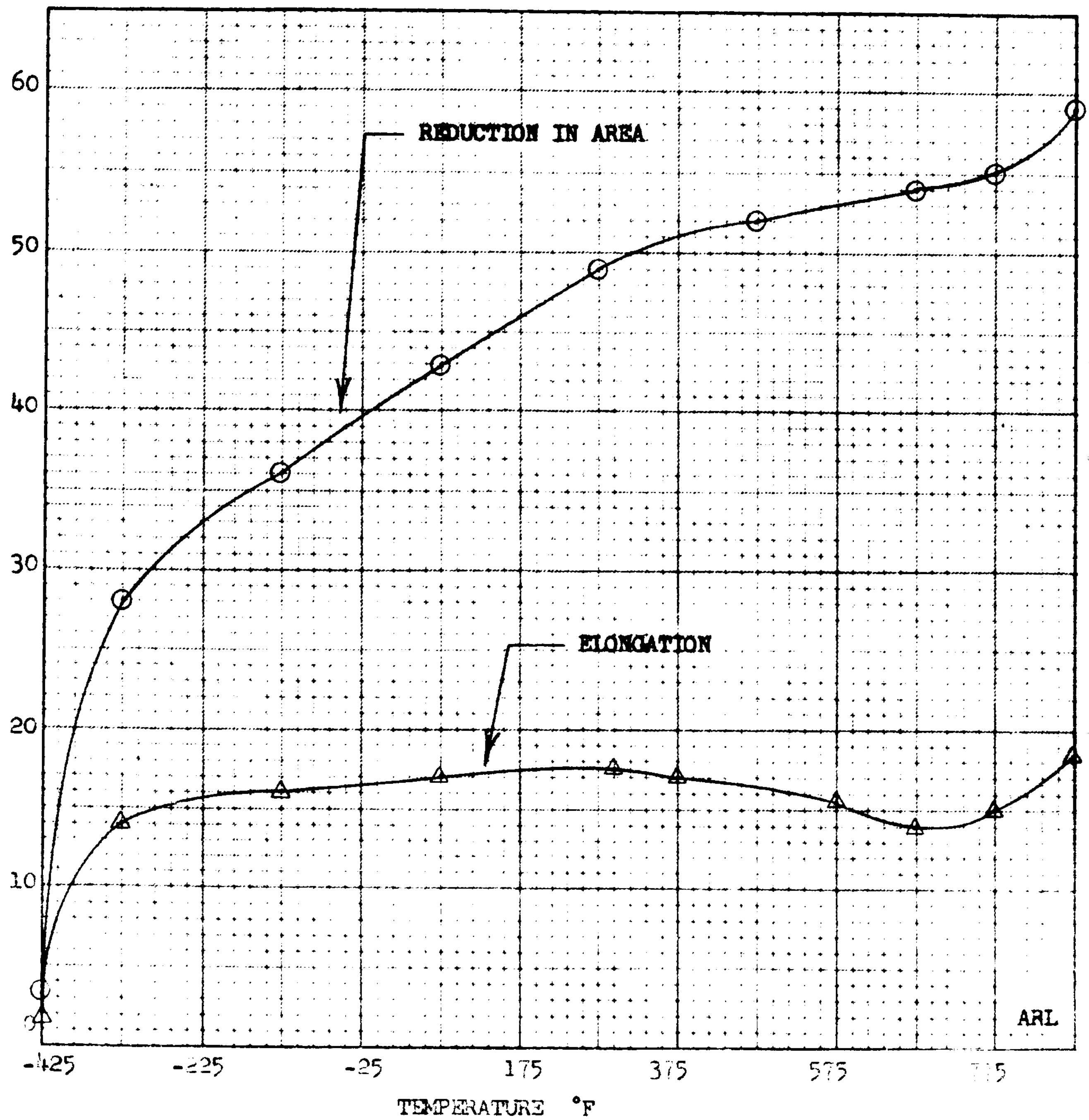
IMPACT ENERGY OF 6Al-4V TITANIUM



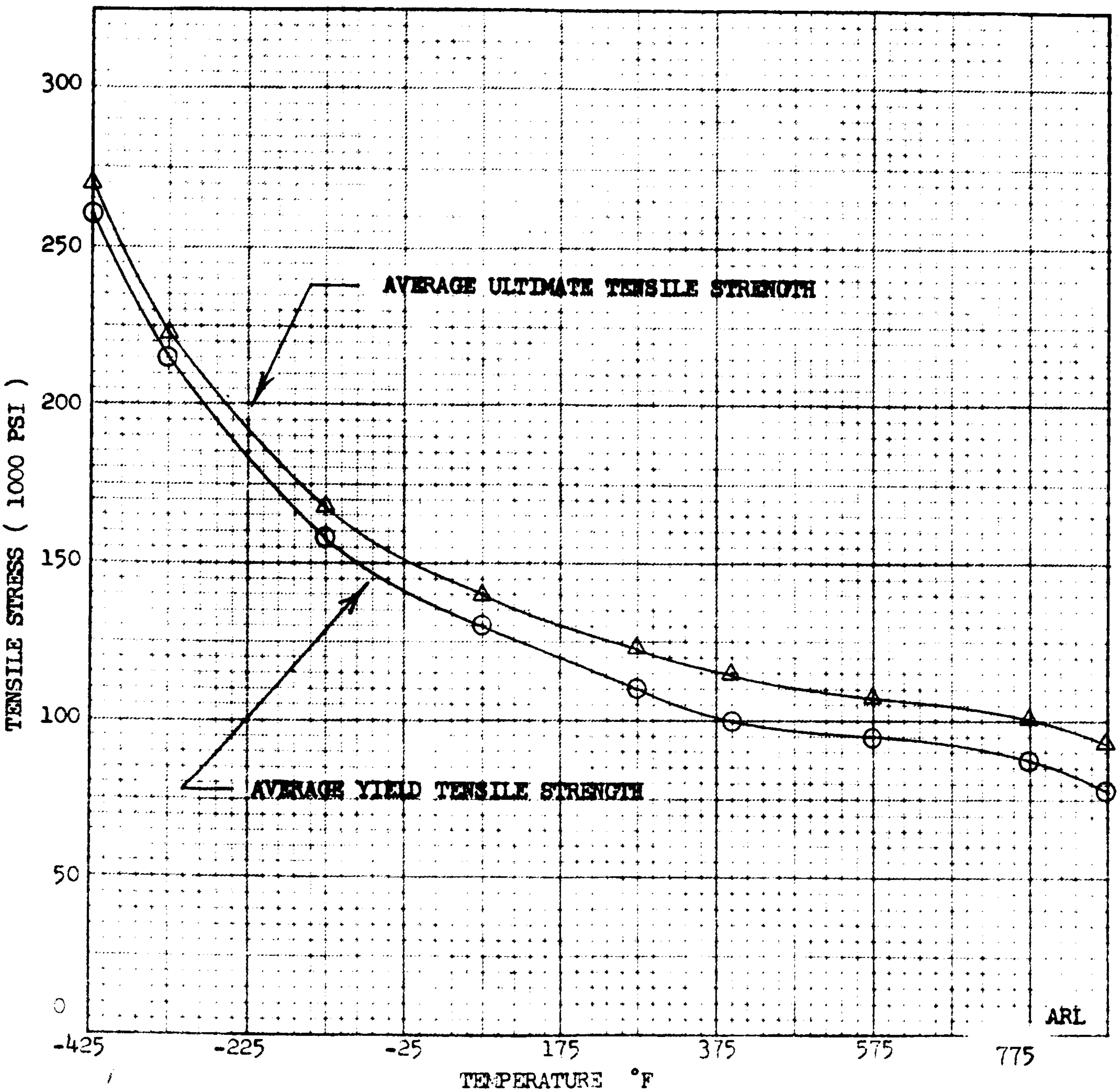
THERMAL CONDUCTIVITY OF 6AL-4V TITANIUM



SPECIFIC HEAT OF 6Al-4V TITANIUM



AVERAGE ELONGATION AND REDUCTION IN AREA OF
6Al-4V ANNEALED TITANIUM



AVERAGE TENSILE STRENGTH OF 6A1-4V ANNEALED TITANIUM

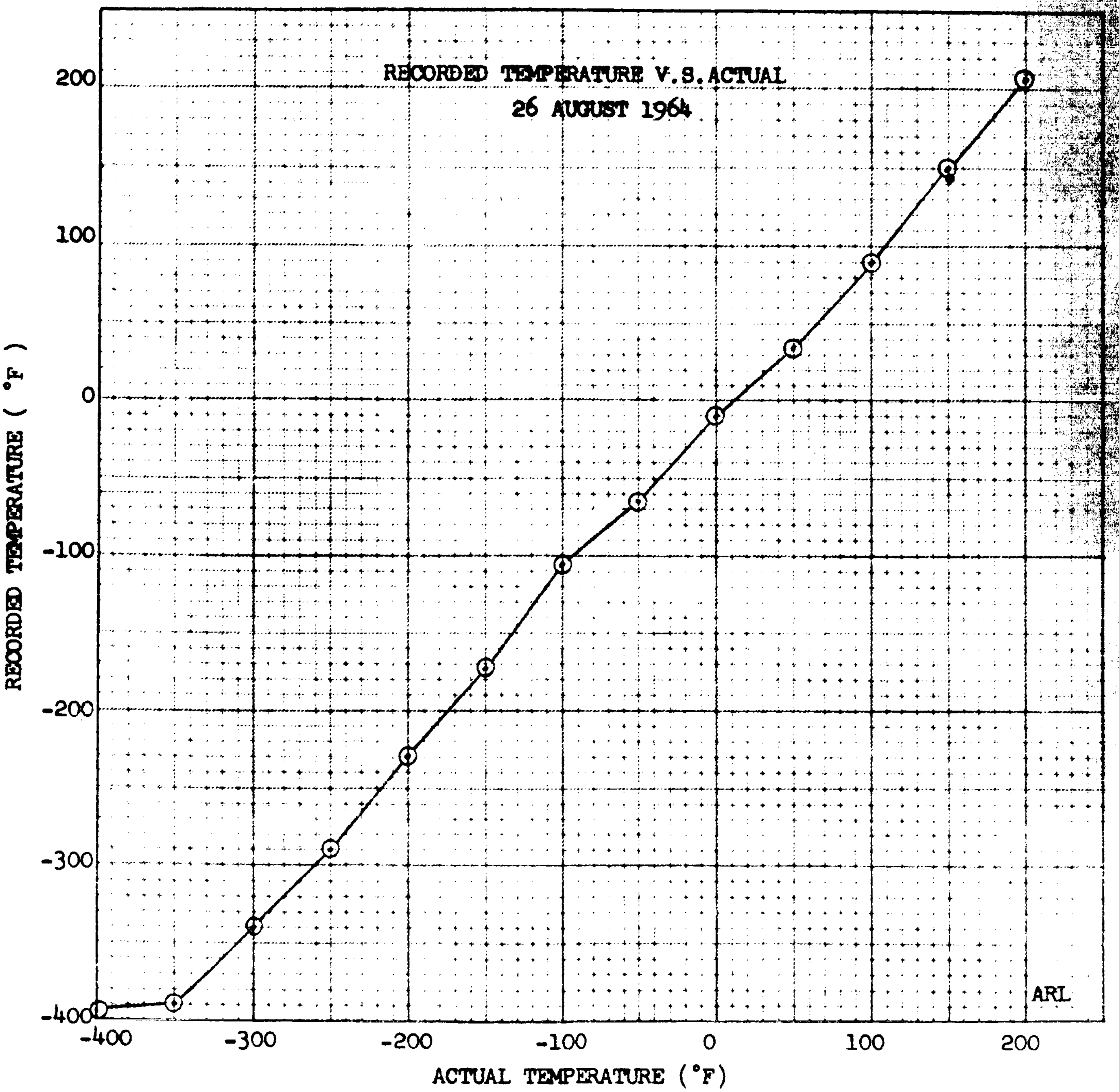
APPENDIX I

BRISTOL TEMPERATURE RECORDERS

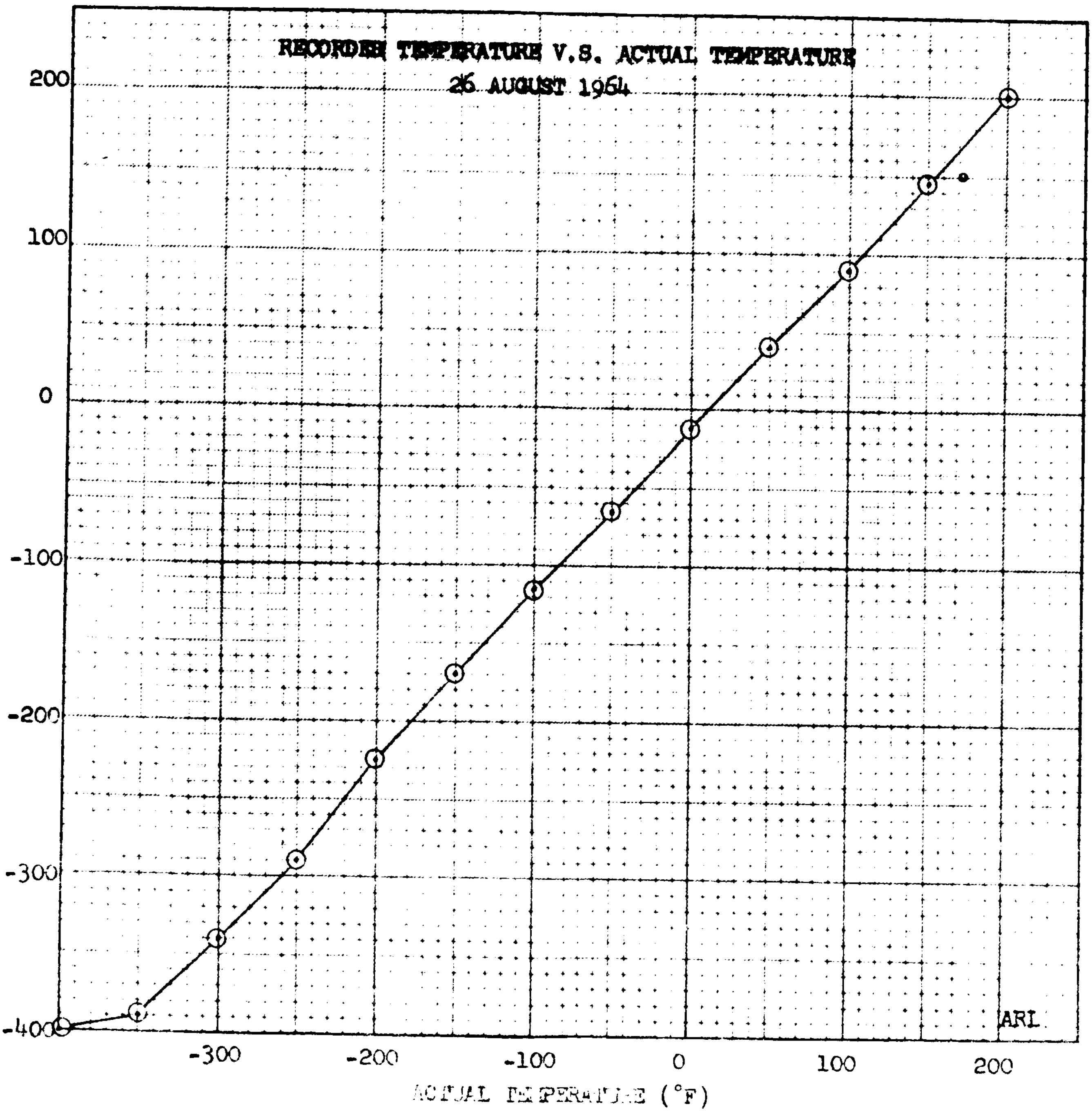
CALIBRATION CURVES

Pages

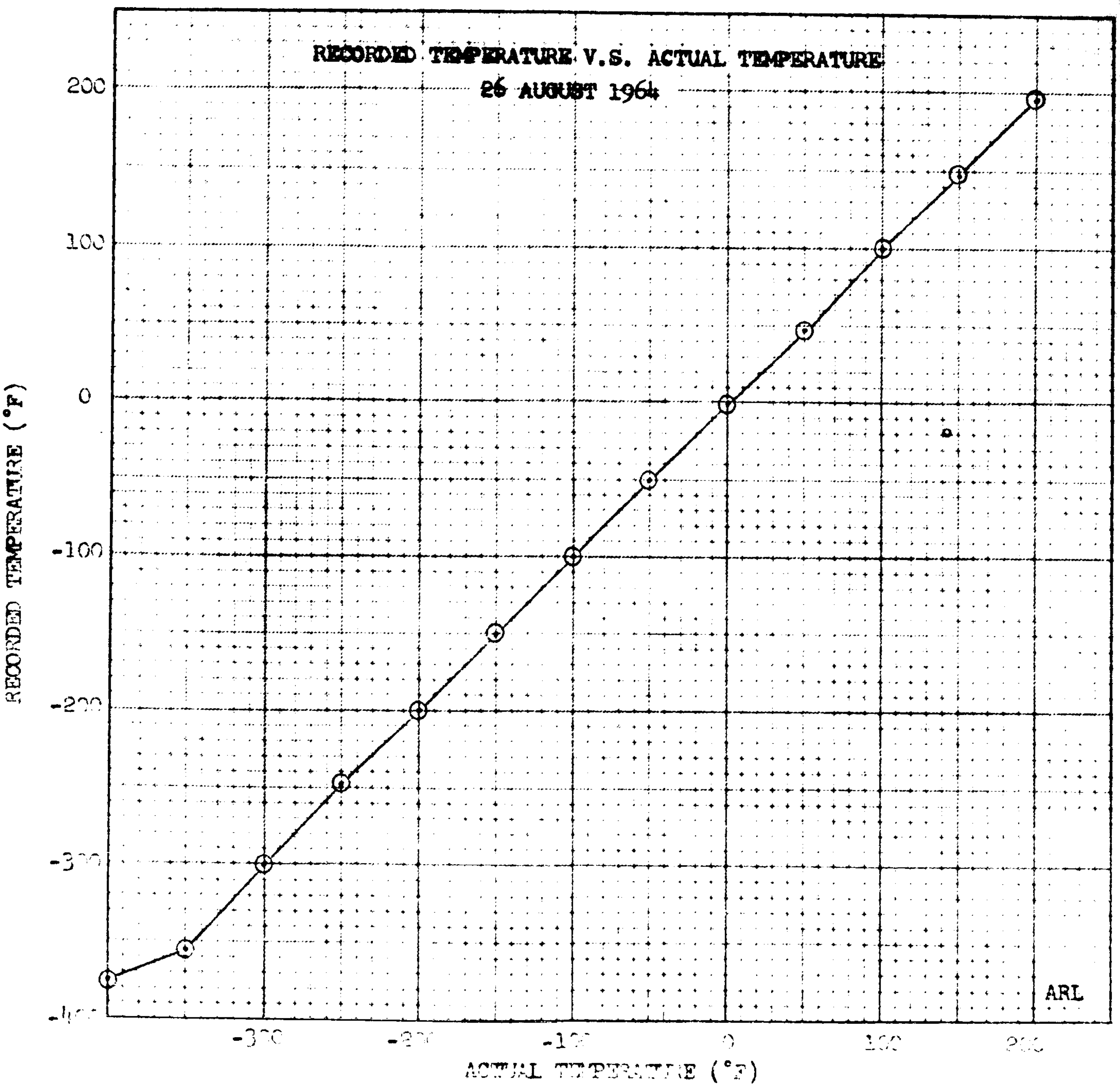
114.0 - 123.0



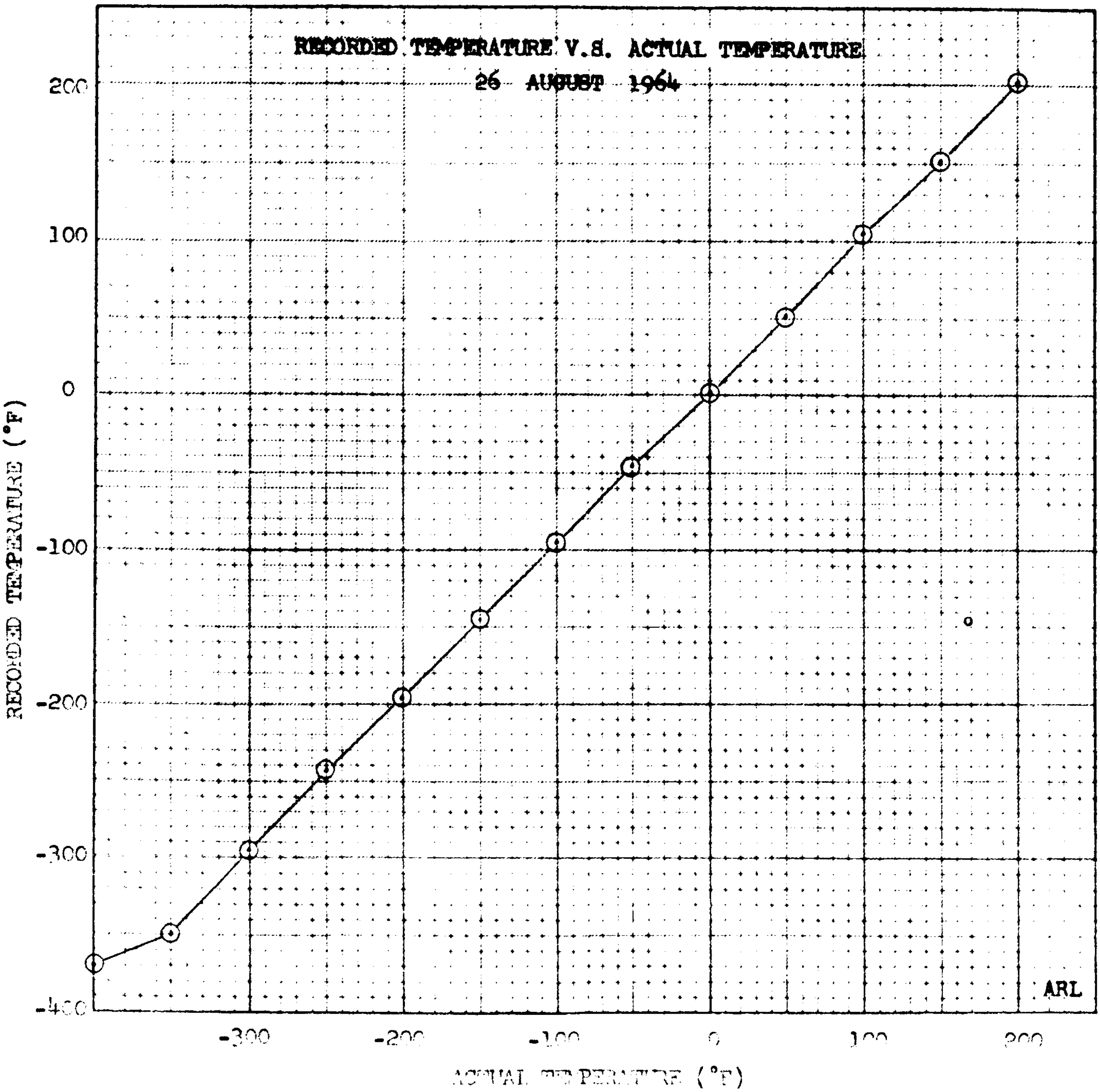
NO.1 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



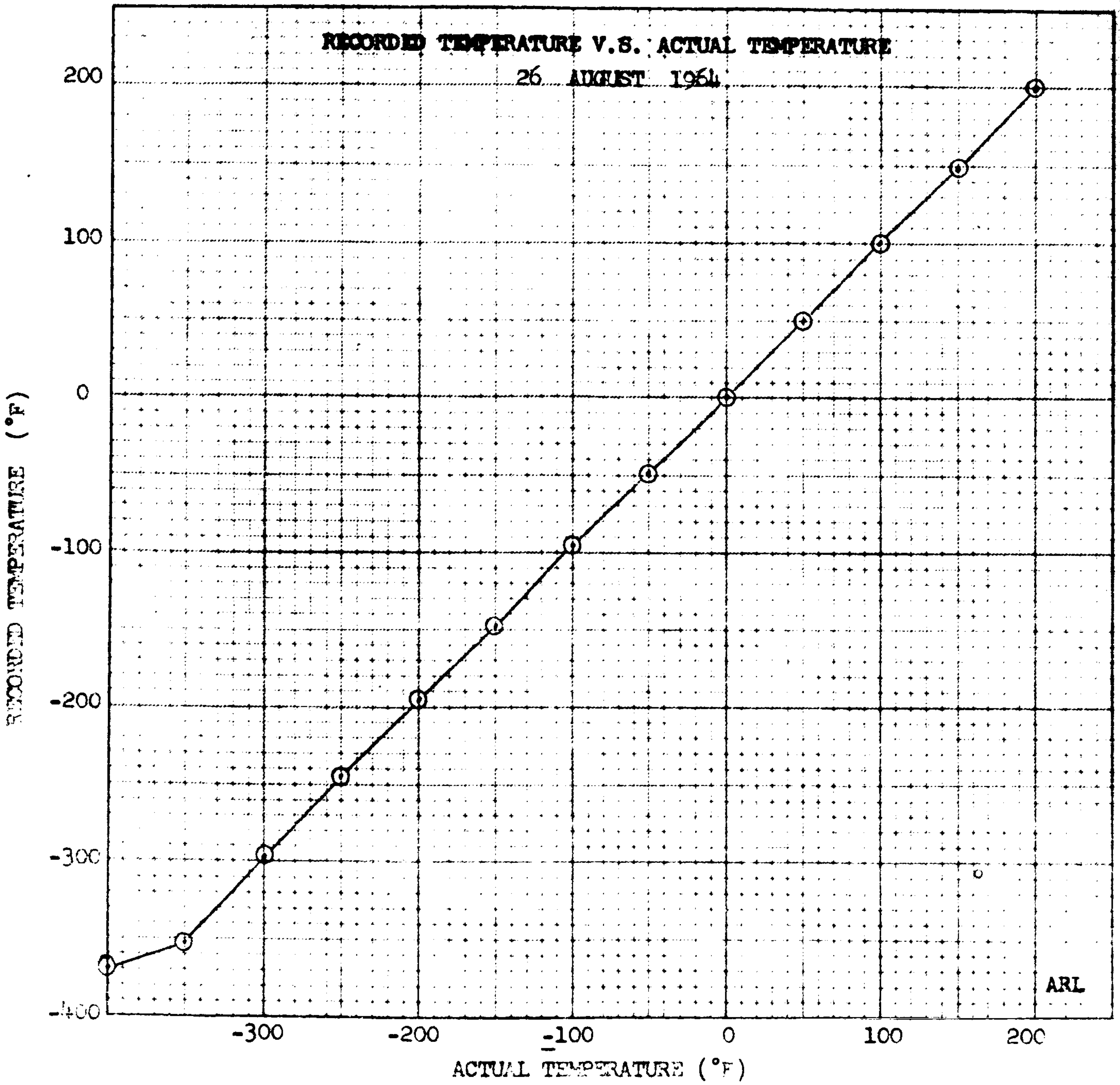
NO. 2 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



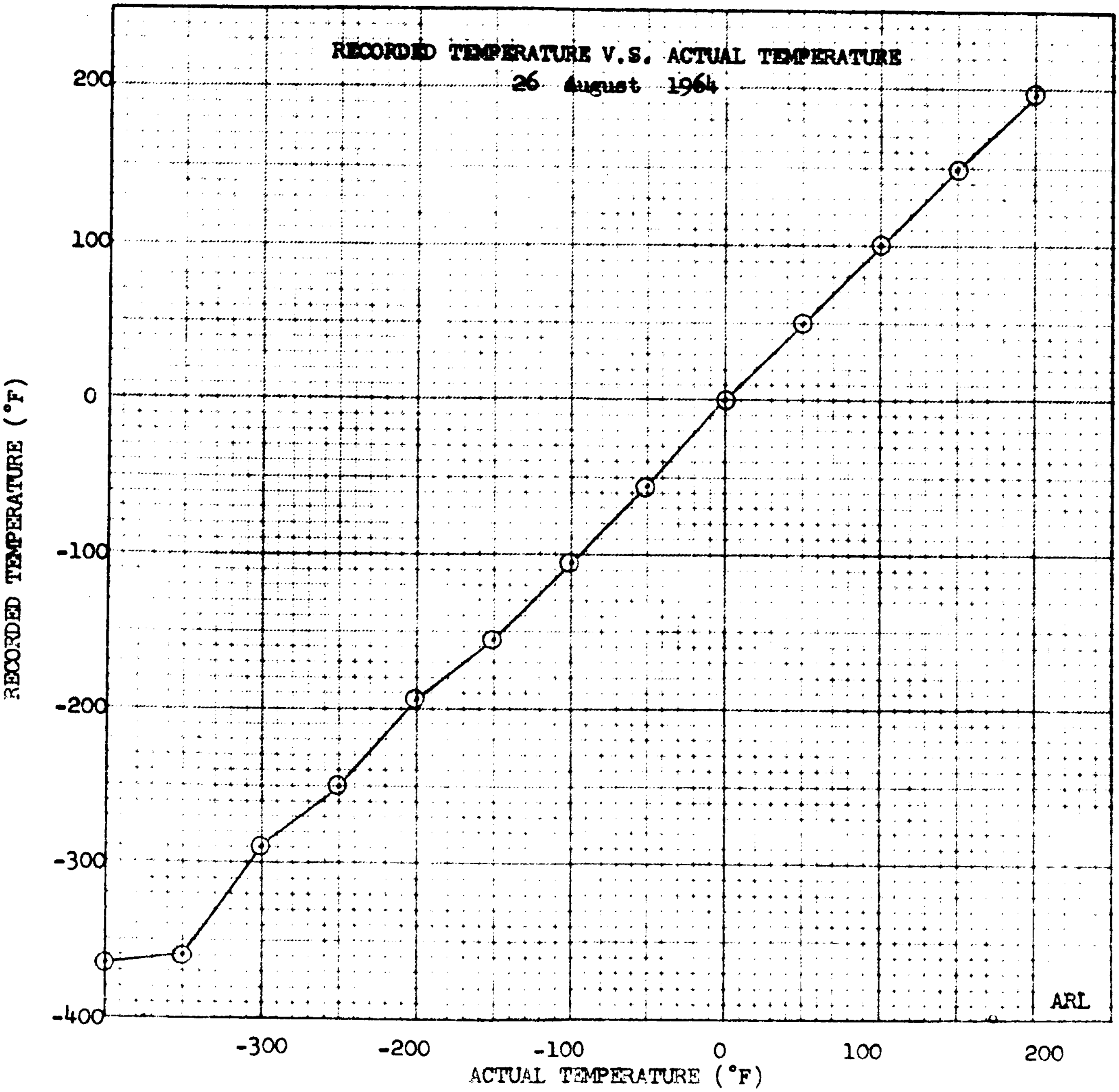
NO. 3 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



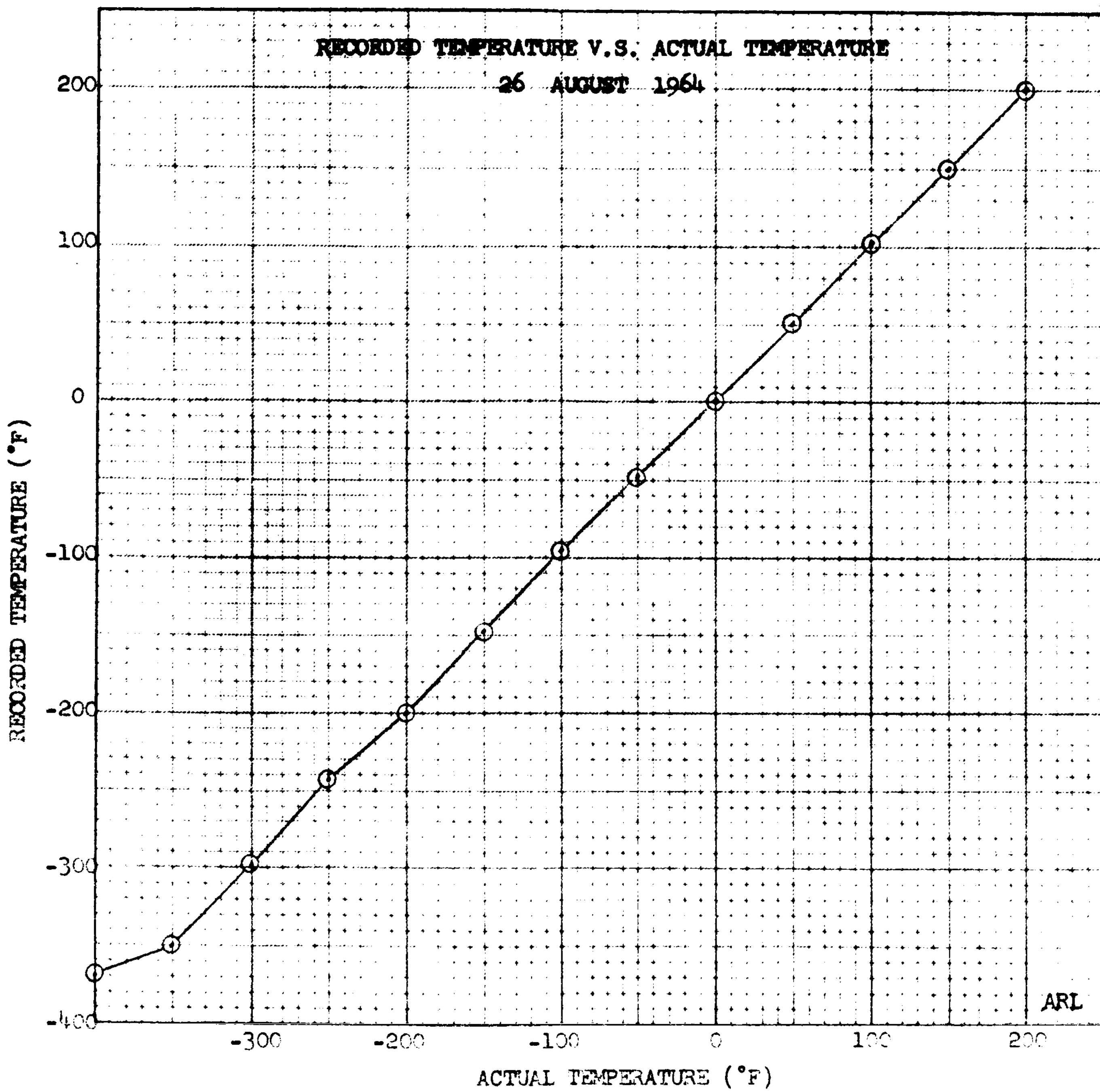
NO. [illegible] BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



NO. 5 [illegible] CORDER
CALIBRATION CURVE



NO. 6 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



NO. 7 BRISTOL TEMPERATURE RECORDER
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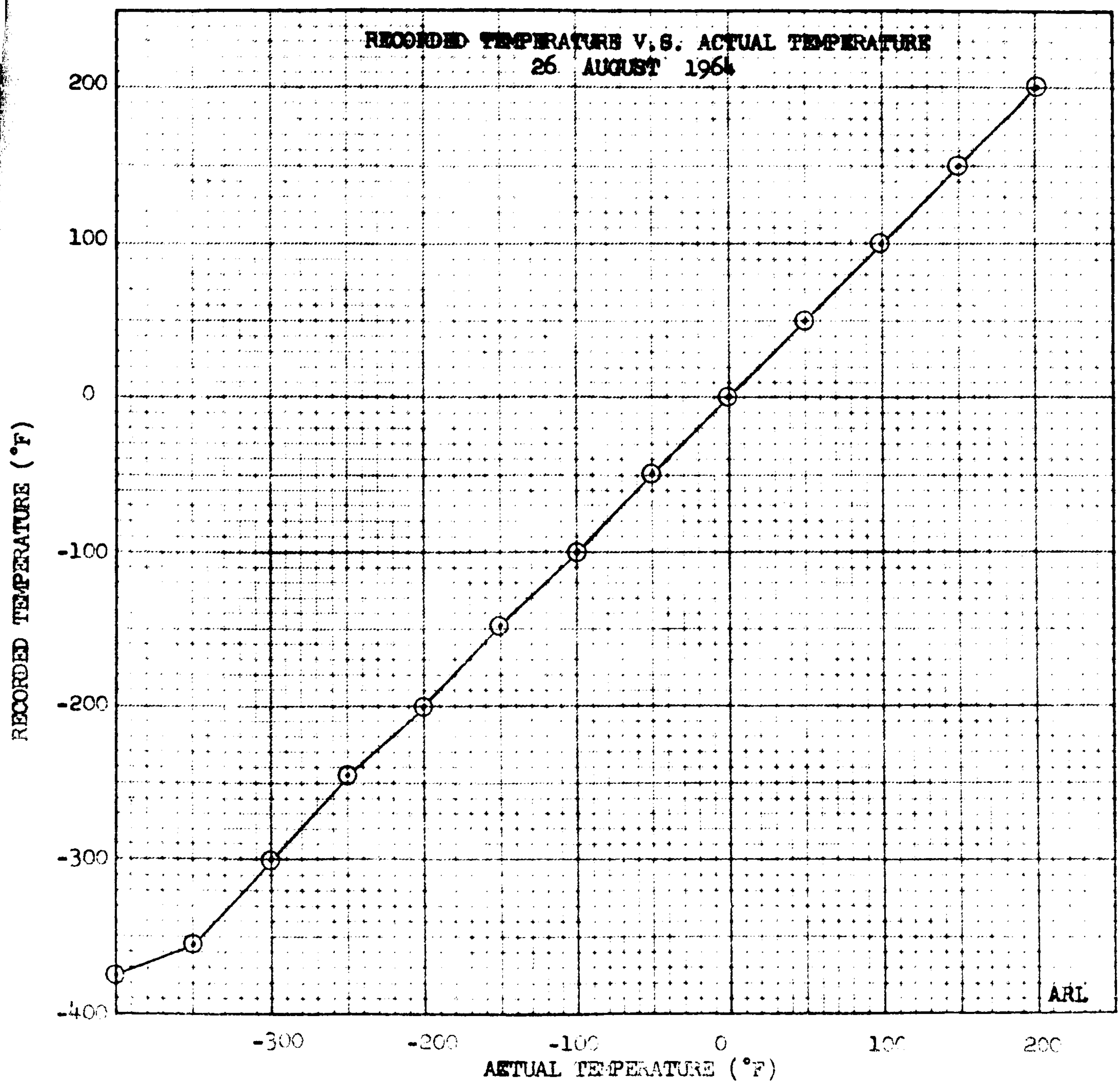


NO. 8 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE

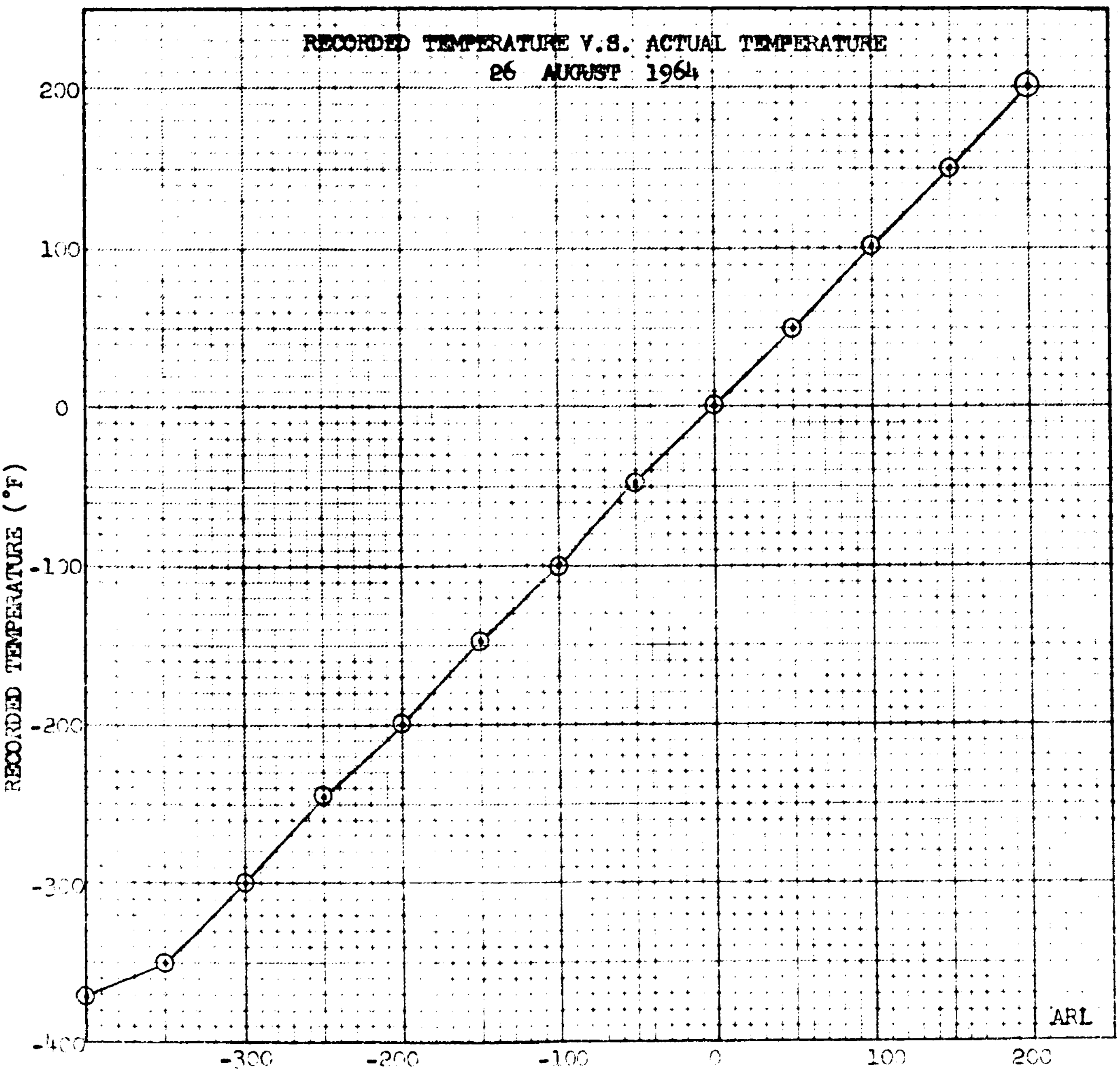
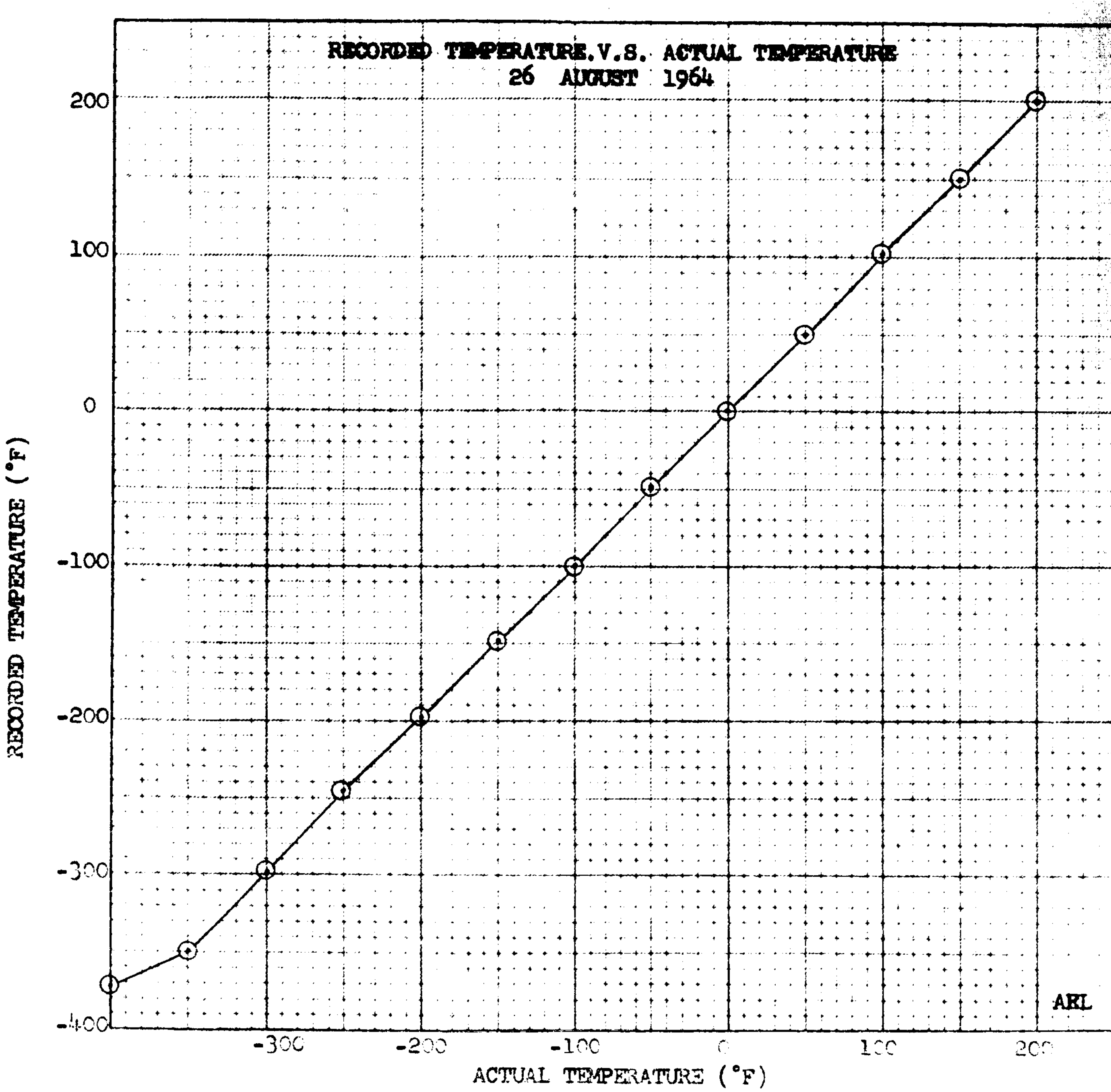
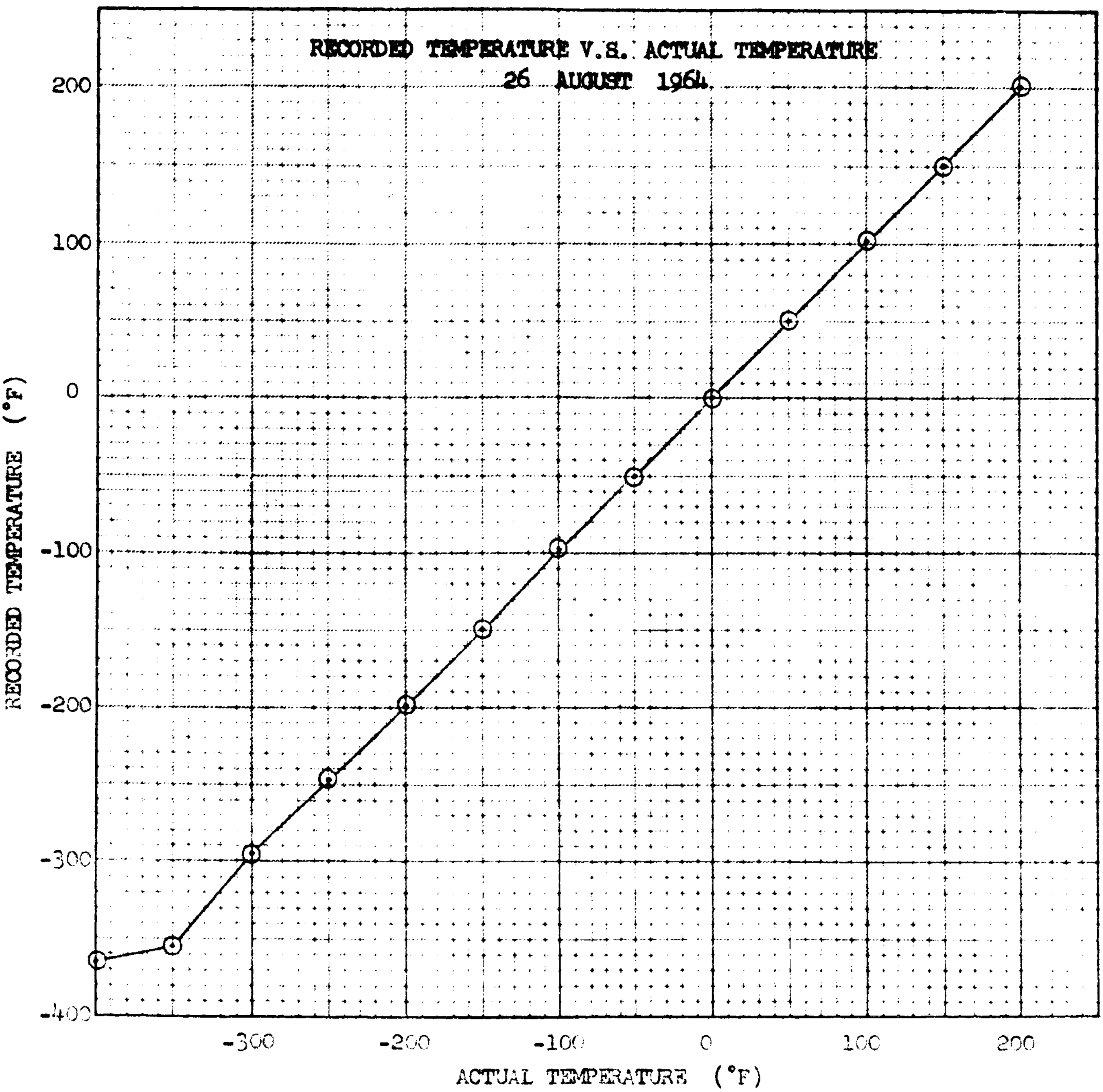


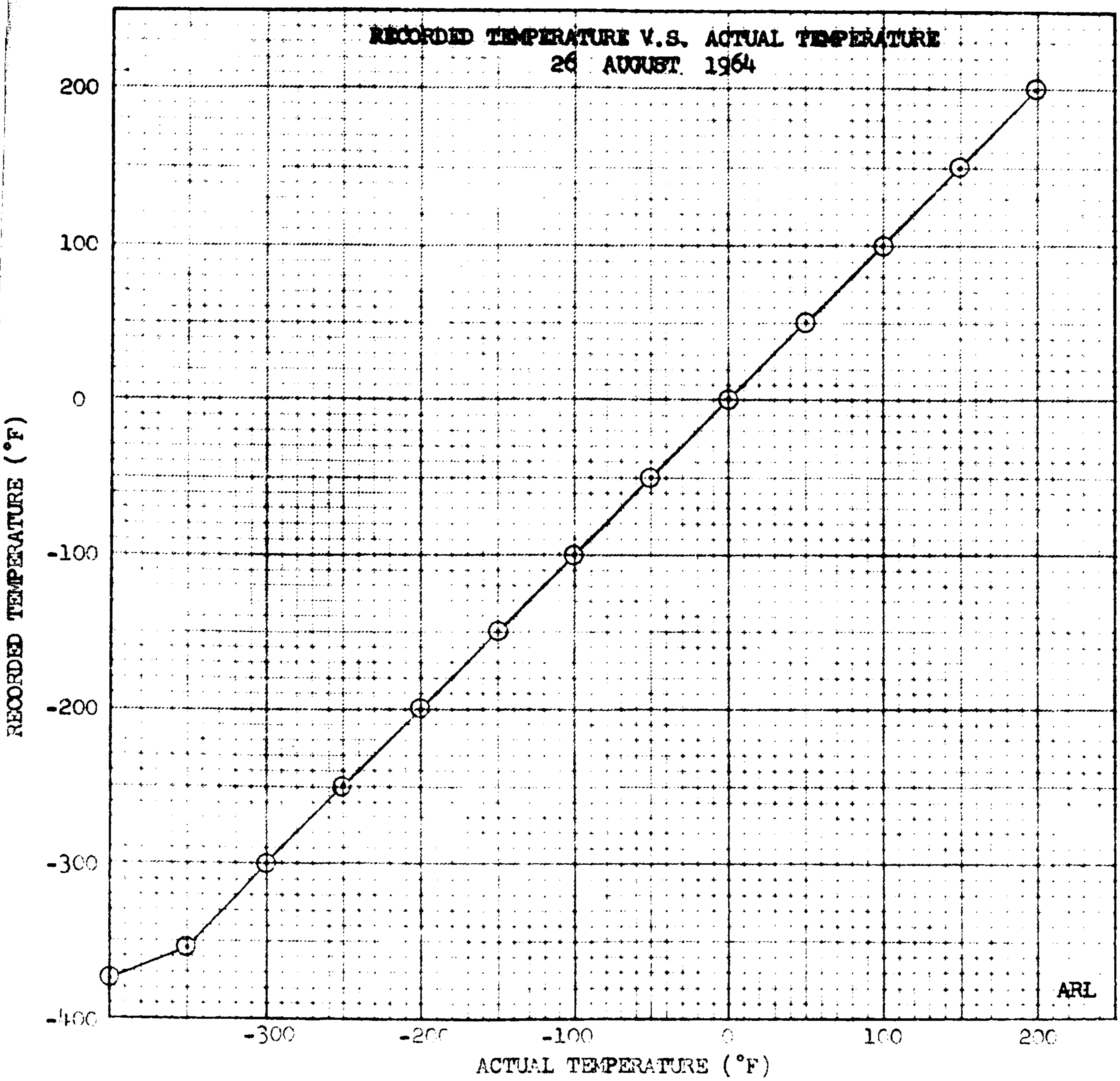
FIG. 9 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



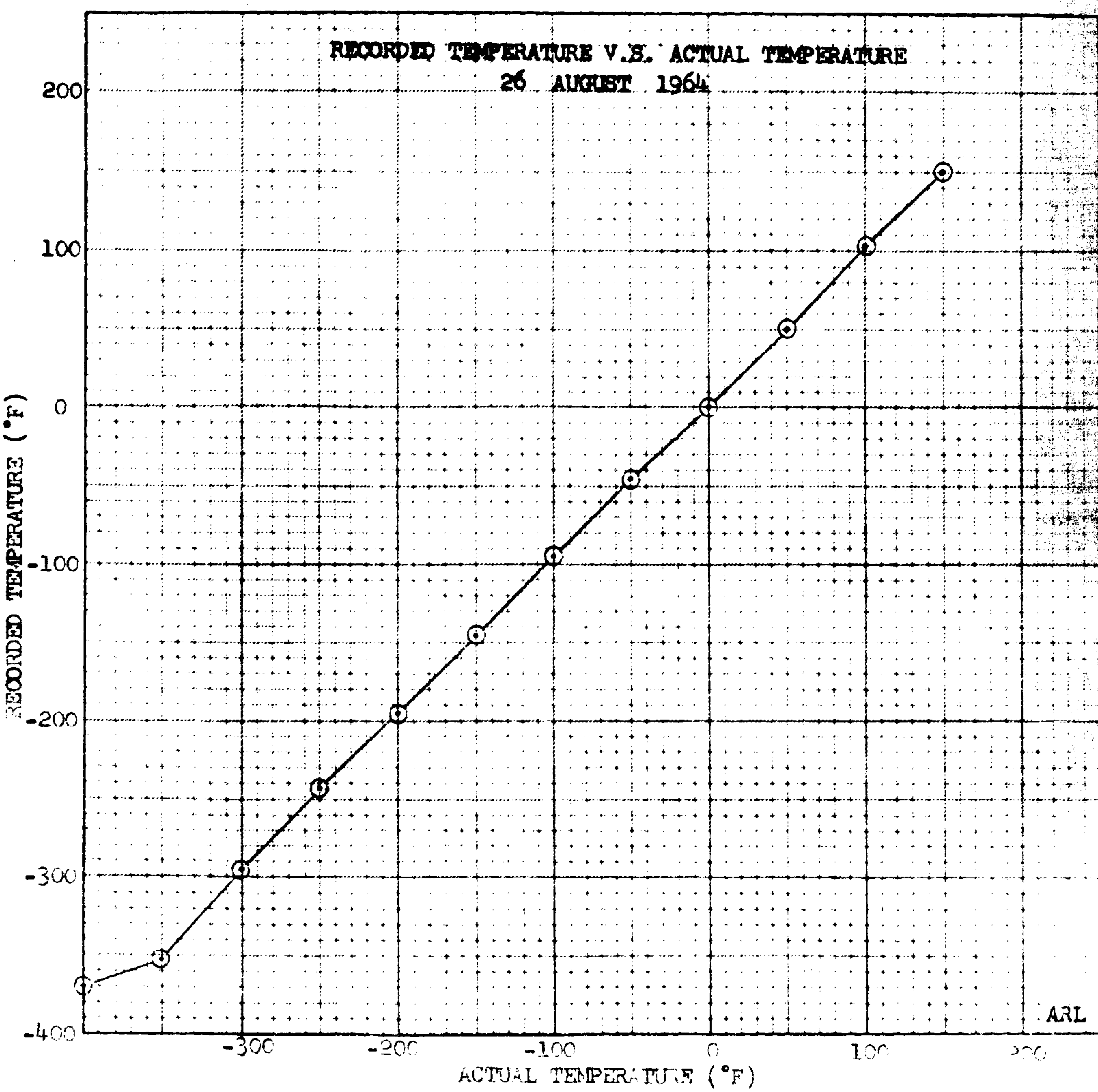
NO. 10 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



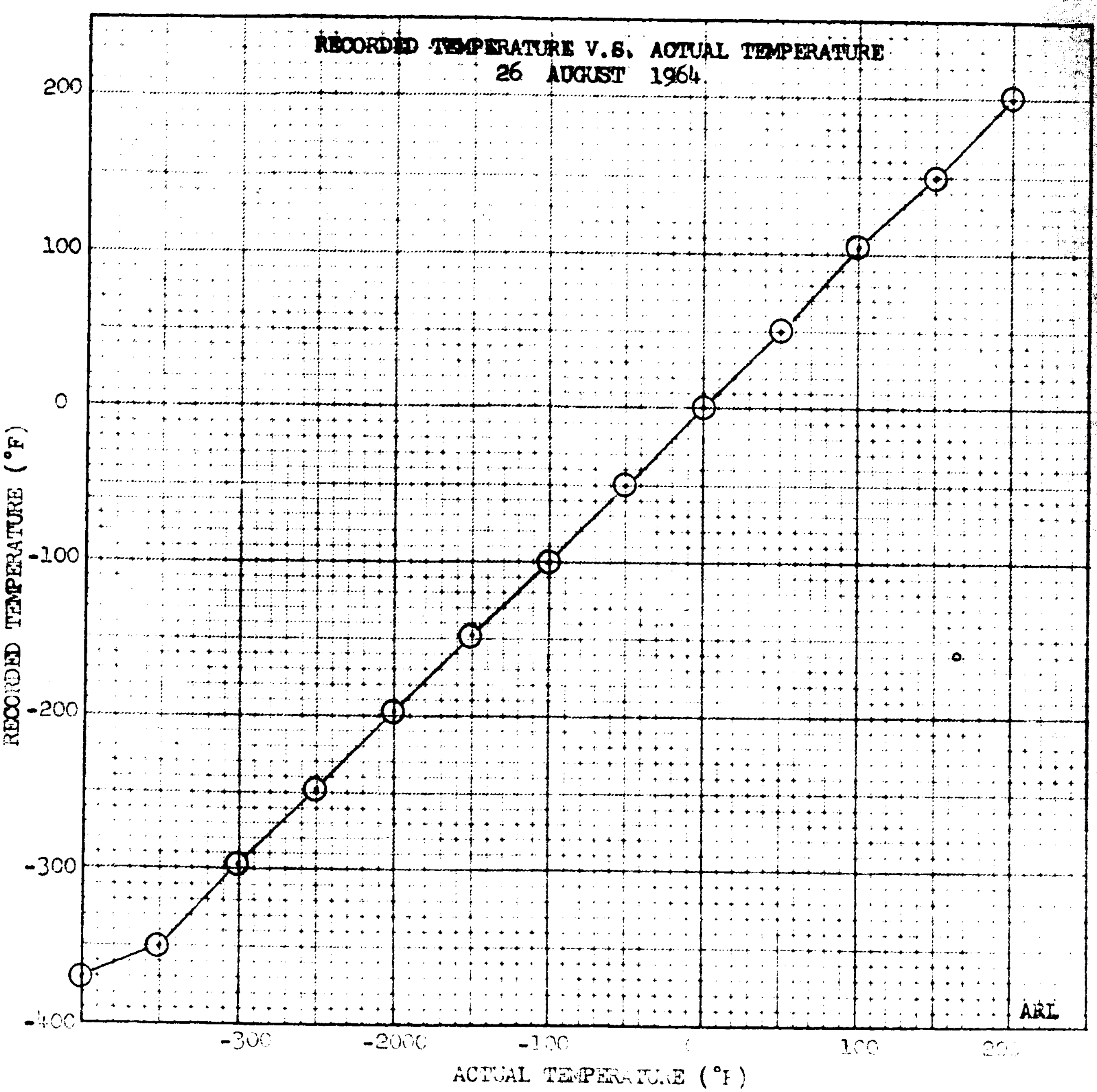
NO. 11 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



NO. 12 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE

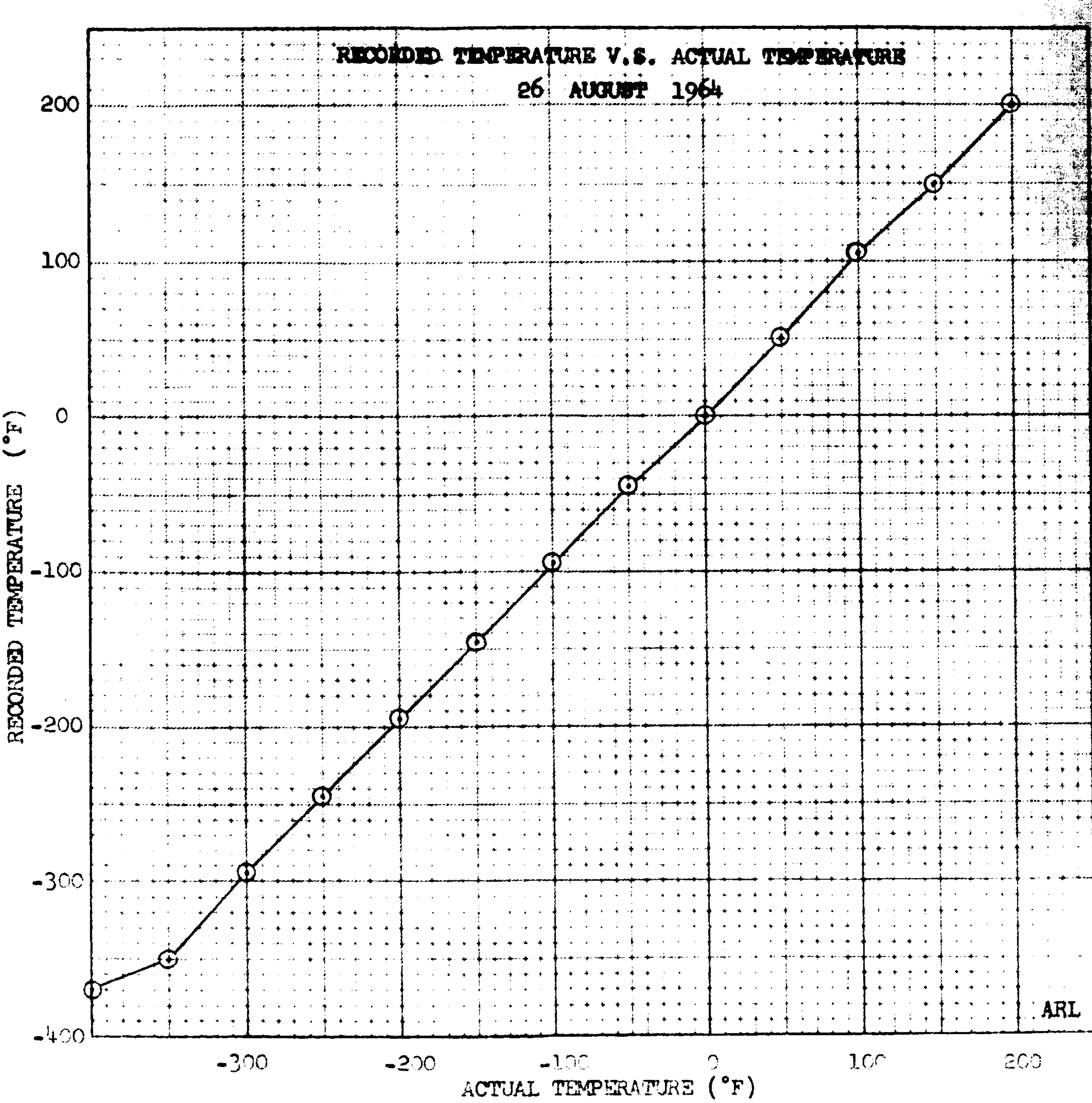


NO. 13 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE



NO. 14 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE

Engineering Report



NO. 15 BRISTOL TEMPERATURE RECORDER
CALIBRATION CURVE

APPENDIX J

FLOWMETER CALIBRATION CURVES

Pages

130.0 - 134.0

TEST DATA - TYPE 20 FLOWMETER
51" CALIBRATOR (RATIO 10[illegible])

Calibrated [illegible] water

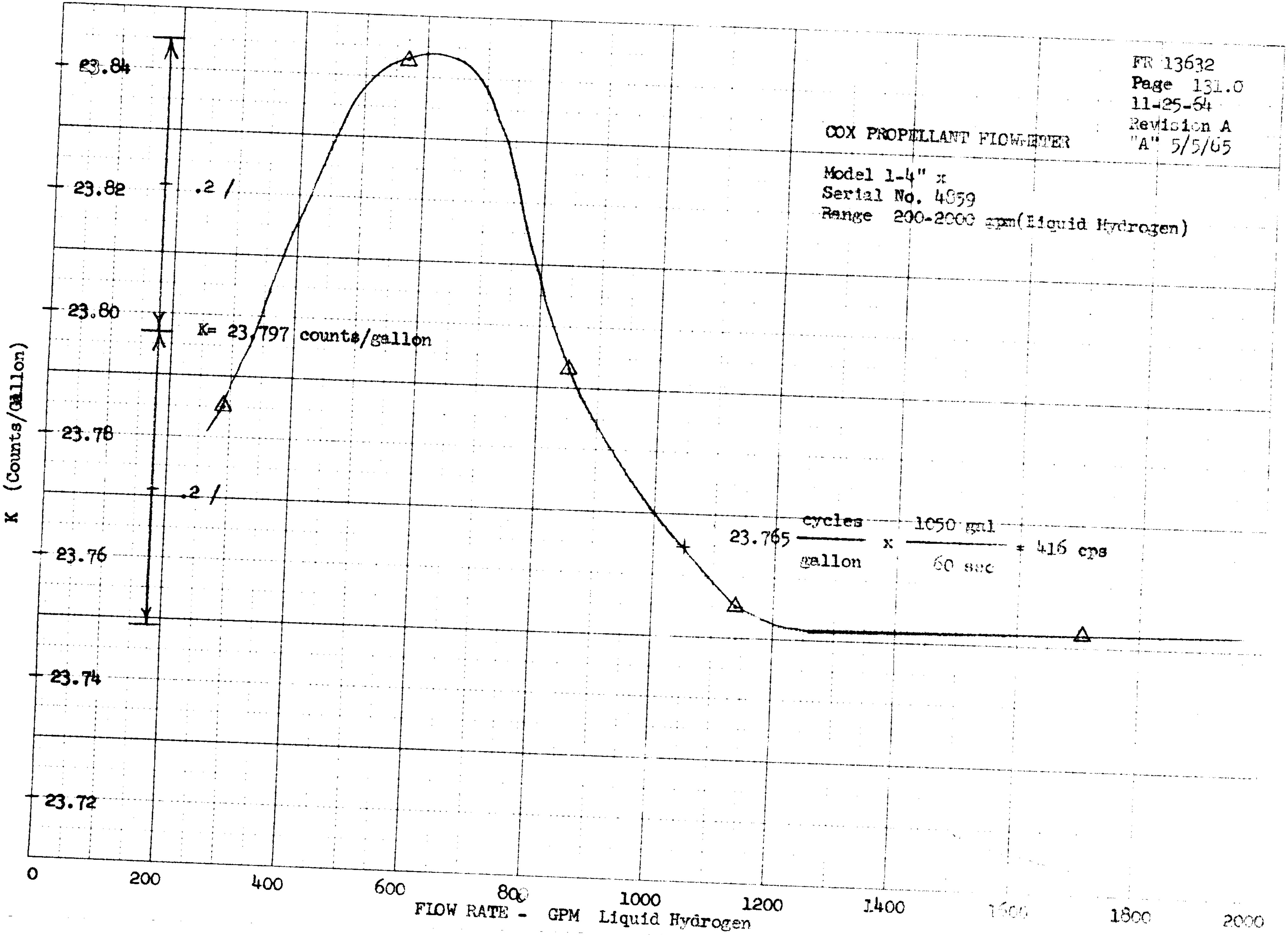
CUSTOMER Beech Aircraft Corp   Customer P/O A - [illegible]   SHOP ORDER [illegible]

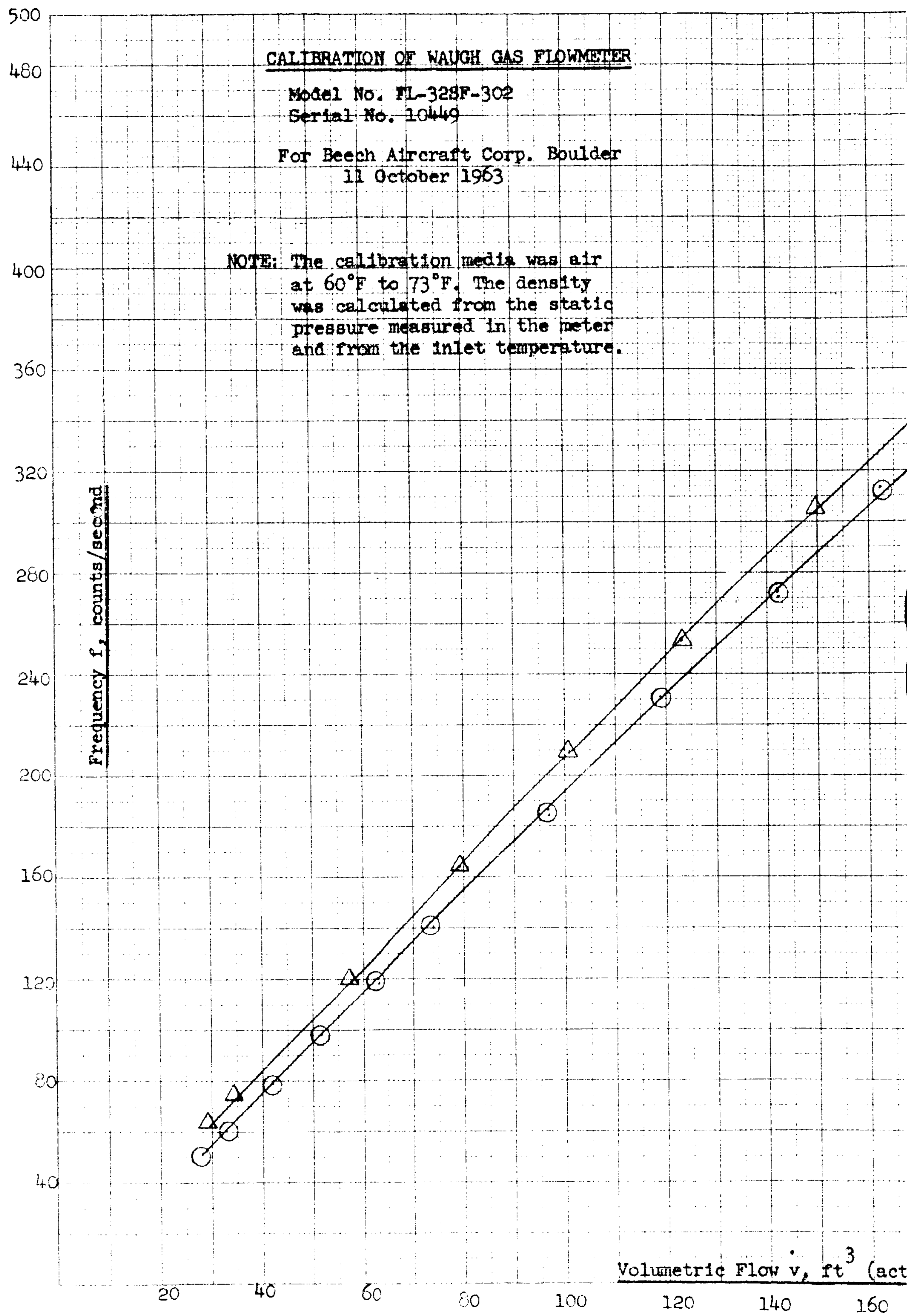
MODEL NO. 1 - 4" X   SERIAL NO. [illegible]   RANGE [illegible]   BLADES [illegible]

PICKUP TYPE Cox 82414A-1A/7   OBSERVER X   DATE [illegible]

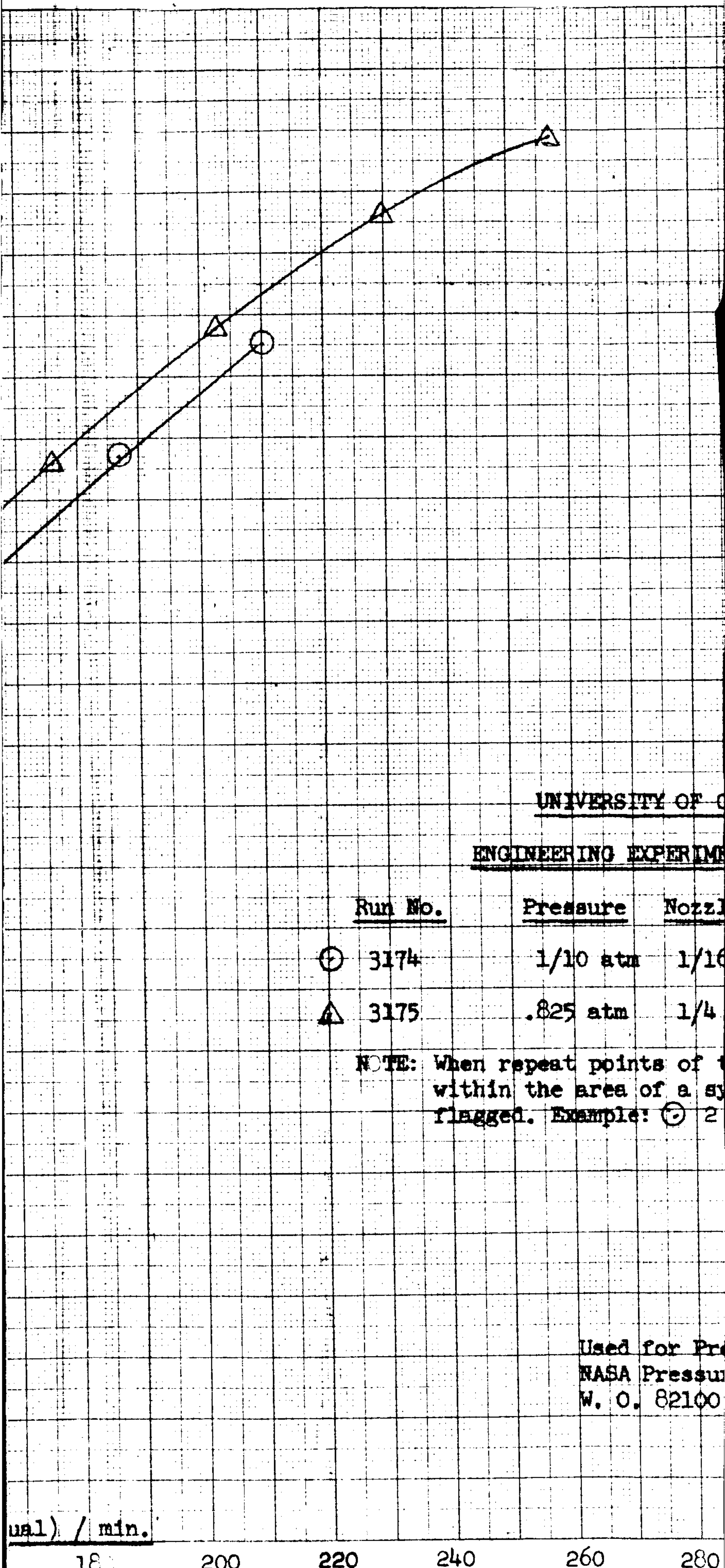
Pulse Rate CPS	Tare Wt. Lbs.	Pan Wt. Lbs.	Total Counts	Weigh Time Sec.	Output Volts MV	Flow Temp. °F	Weight Flowed Lbs.	Vol. Flowed	CPG Calib. Factor	Meter Δ P PSI	PPH	GPM	Remarks
30		1	3071 3078 Av 3074.5	102.286 102.418 A 102.352	50	66	1076	129.26	23.785		37,846	75.77[illegible]	[illegible].324 S.G. 9995
60		2	6165 6163 A 6164	103.68 103.148 A 103.158	100	66	2152	258.52	23.843				
90		2	6152 6150 A 6151	68.442 68.421 Av68.432	150	66	2152	258.52	23.793				
120		2	6143 6139 A 6141	51.061 51.062 Av51.0615	200	65	2152	258.51	23.795				[illegible].3245
180		2	6137 6141 A 6139	34.082 34.110 Av 34.096		64	2152	258.46	23.752				[illegible].32[illegible] S.G.999[illegible]
240		4	12275 12269 A 12271	51.428 51.686 Av 51.507		64	4304	516.93	23.738				
[illegible]		4	12279 12266 A12273.5	41.781 41.483 Av 41.632		64	4304	516.93	23.[illegible]3				
[illegible]		4	12270 12267 A122[illegible].5	34.549 34.828 Av 34.6685	600	64	4304	516.93	23.760				
[illegible]		4	12296 12263 A12269.5	29.257 29.348 Av 29.3025		64	4304	516.93	23.774		528,[illegible]	1058.5	

[illegible] factor = counts ÷ wt. flowed
[illegible] ÷ sp. wt. [illegible] factor = counts ÷ vol. flowed


COX PROPELLANT FLOWMETER
Model 1-4" x
Serial No. 4859
Range 200-2000 gpm(Liquid Hydrogen)
K= 23.797 counts/gallon
.2 /
.2 /
23.765 cycles/gallon x 1050 gal/60 sec = 416 cps
K (Counts/Gallon)
23.84
23.82
23.80
23.78
23.76
23.74
23.72
0
200
400
600
800
1000
1200
1400
1600
1800
2000
FLOW RATE - GPM Liquid Hydrogen


CALIBRATION OF WAUGH GAS FLOWMETER
Model No. FL-32SF-302
Serial No. 10449
For Beech Aircraft Corp. Boulder
11 October 1963
NOTE: The calibration media was air at 60°F to 73°F. The density was calculated from the static pressure measured in the meter and from the inlet temperature.
Frequency f, counts/second
Volumetric Flow v, ft^3 (act
500
480
440
400
360
320
280
240
200
160
120
80
40
20
40
60
80
100
120
140
160

132 -1



UNIVERSITY OF C
ENGINEERING EXPERIME
Run No.
Pressure
Nozzl
3174
1/10 atm
1/16
3175
.825 atm
1/4
NOTE: When repeat points of t
within the area of a sy
flagged. Example: 2
Used for Pr
NASA Pressu
W. O. 82100
ual) / min.
18
200
220
240
260
280

132 C

COLORADO

NT STATION

e	Nom. Density
5	0.0075 lb/ft^3
	0.0620 lb/ft^3

he same density fall
mbol, the symbol is
points.

pressurization Flow
ization Study

300 320 340 360

Arnberg

E. J. T. 132.A

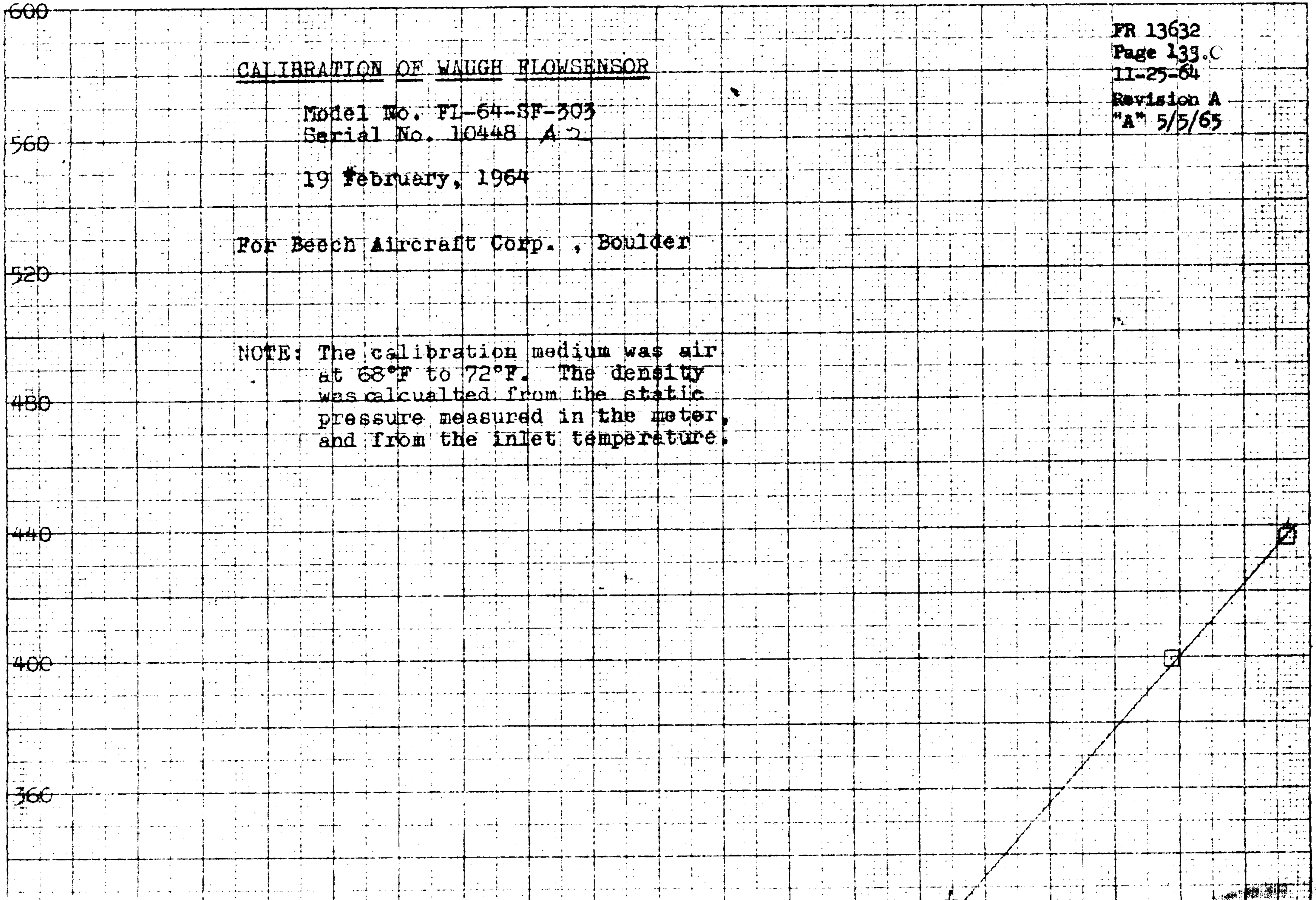
CALIBRATION OF WAUGH FLOWSENSOR

Model No. FL-64-SF-303
Serial No. 10448 A 2

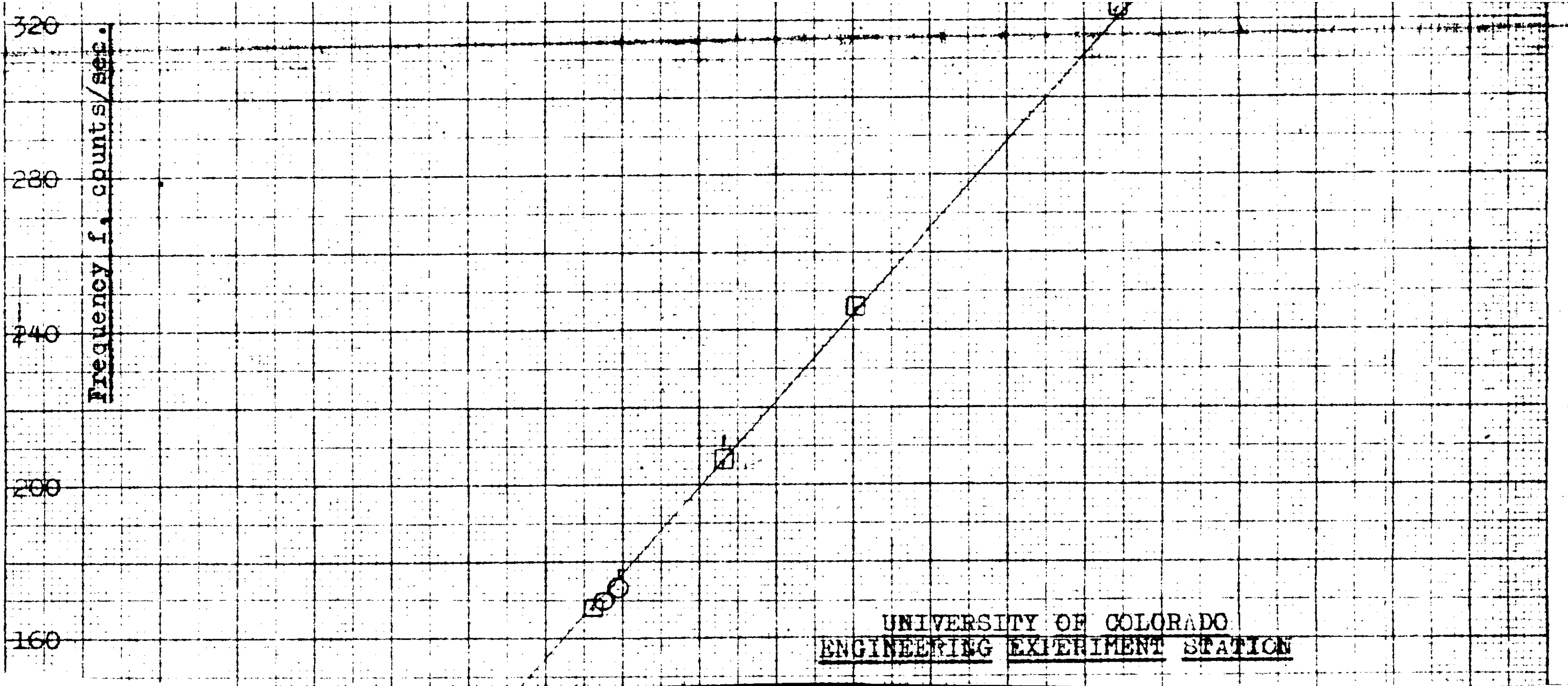
19 February, 1964

For Beech Aircraft Corp. , Boulder

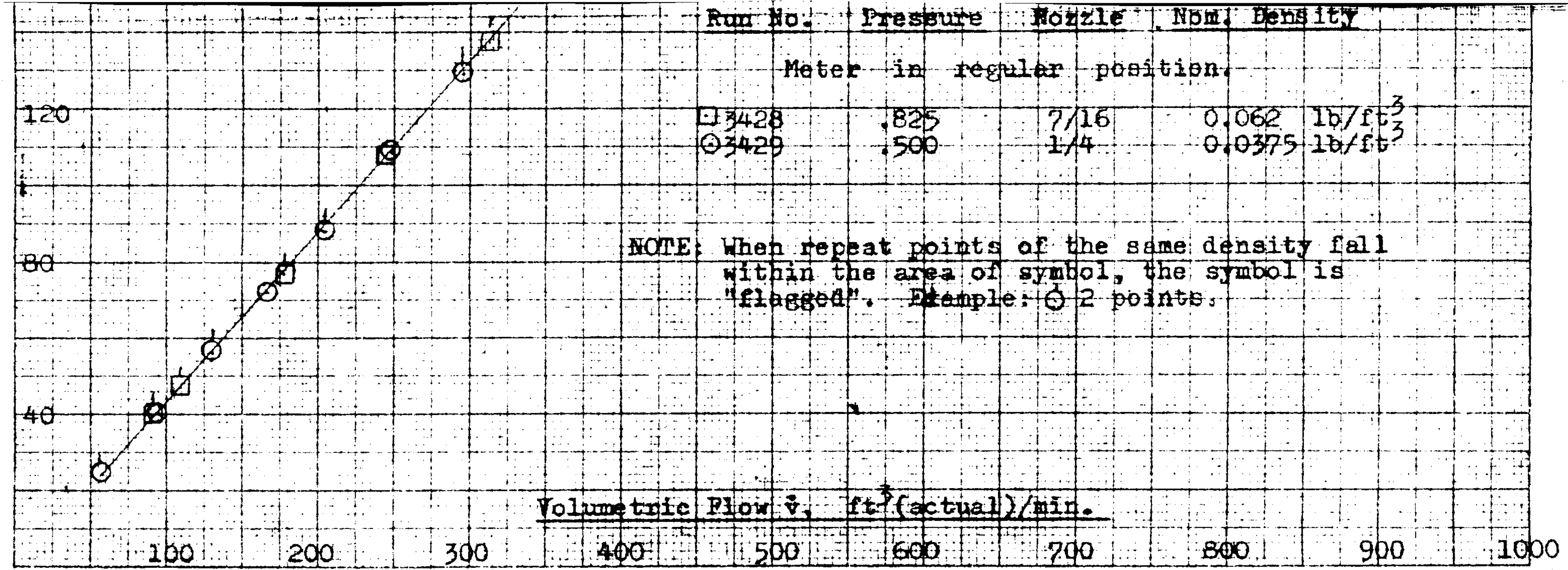
NOTE: The calibration medium was air at 68°F to 72°F. The density was calcualted from the static pressure measured in the meter, and from the inlet temperature.



133 (2)



320
280
240
200
160
Frequency f, counts/sec.
UNIVERSITY OF COLORADO
ENGINEERING EXPERIMENT STATION



E.J.T.

Used For Pressurization Flow
NASA Pressurization Study
W. O. 82100

133-2

FR 13632
Page 134.0
11/25/64
Revision A
"A" 5/5/65

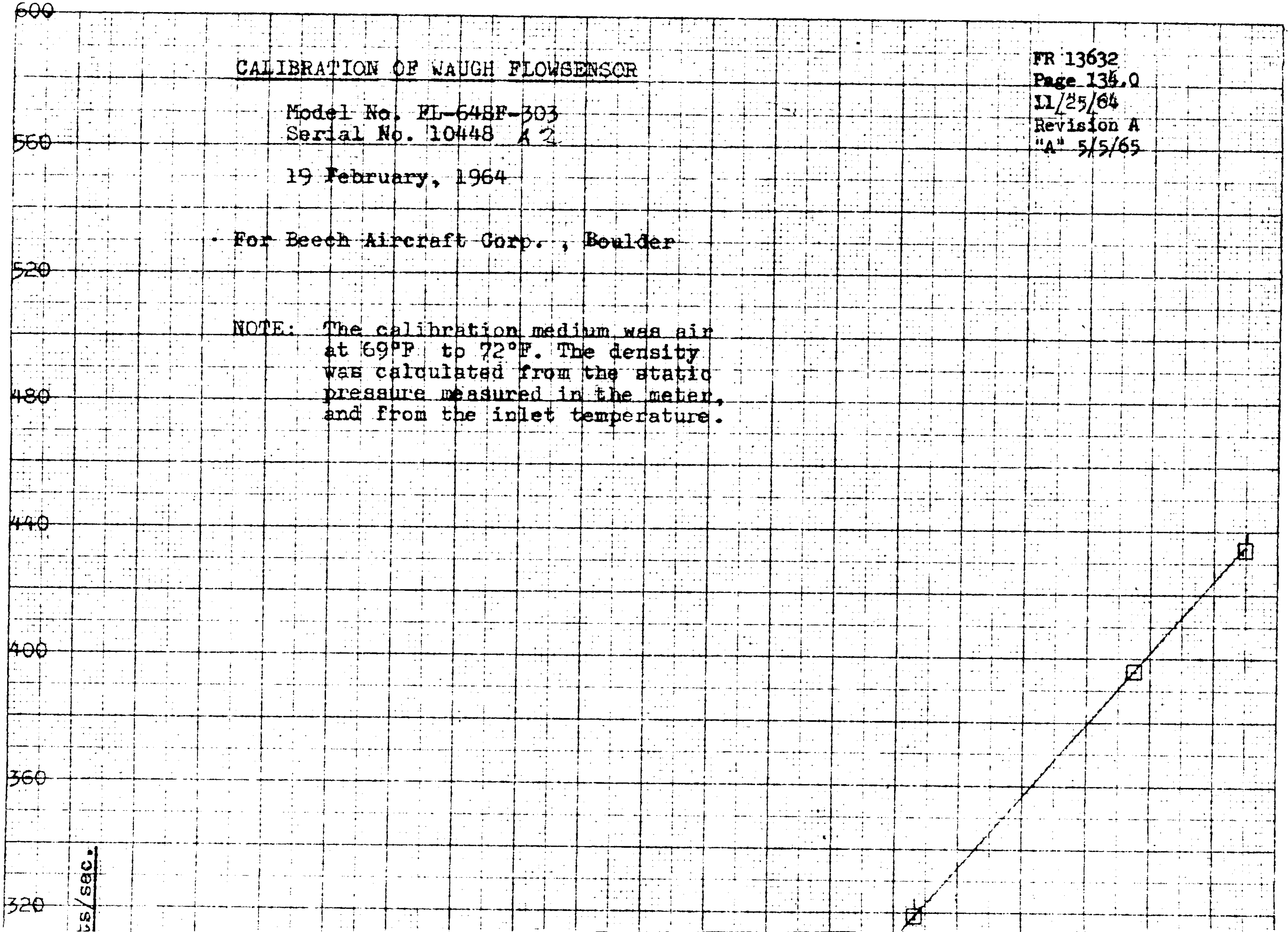
CALIBRATION OF WAUGH FLOWSENSOR

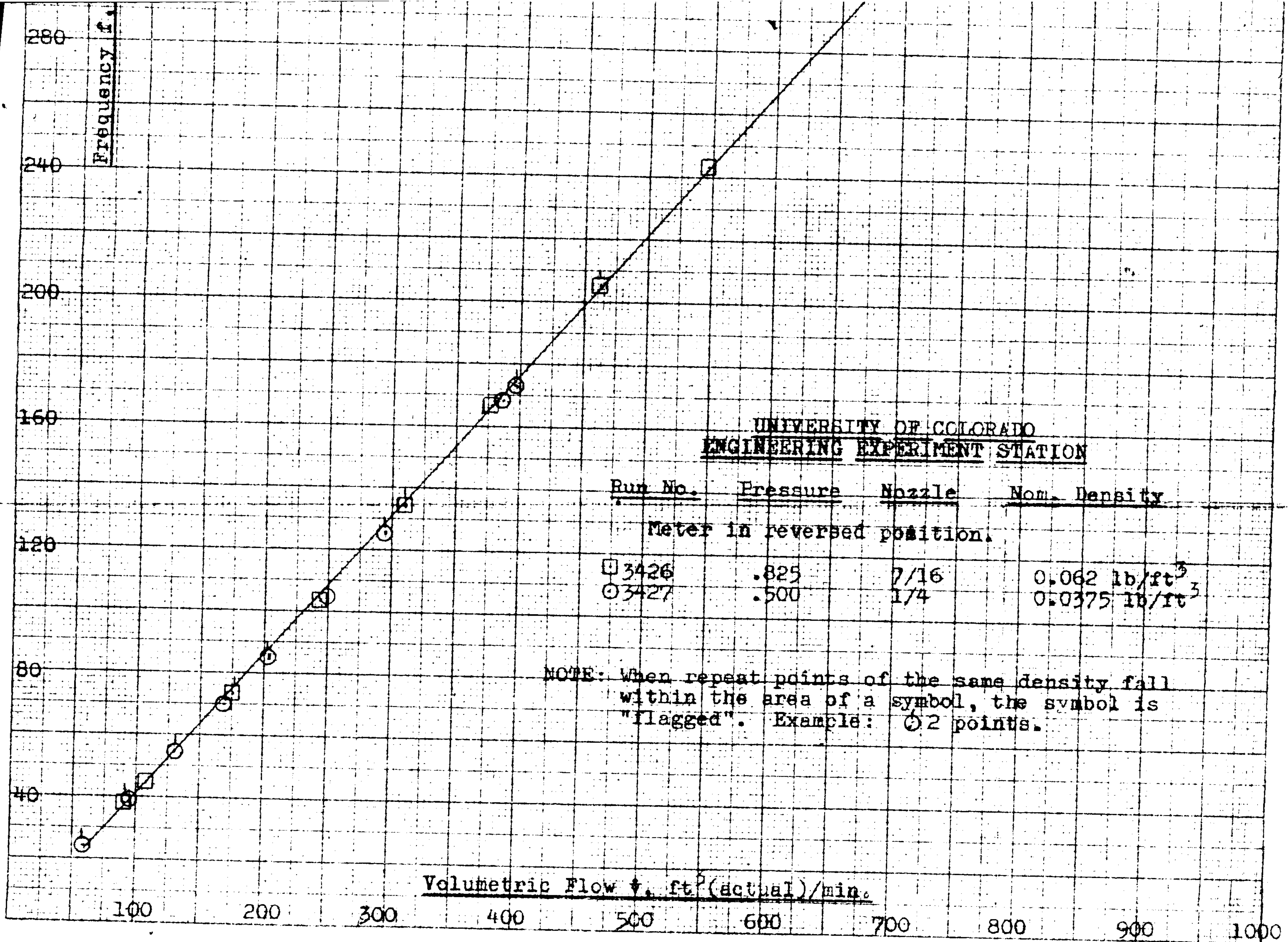
Model No. FL-648F-303
Serial No. 10448 A2

19 February, 1964

For Beech Aircraft Corp., Boulder

NOTE: The calibration medium was air at 69°F to 72°F. The density was calculated from the static pressure measured in the meter, and from the inlet temperature.





E.J.T.

Used For Vent Flow
NASA Pressurization Study
W. O. 82100

APPENDIX K

NASA SUPPLIED TEST CURVES

Page